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FACILITY SAFETY STUDY

A REPORT FOR NASA

MARSHALL SPACE FLIGHT CENTER

CONTRACT # WAS8-32812

PREPARED BY

INTEGRATED CIRCUIT ENGINEERING CORPORATION
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OCTOBER 1979

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INTEGRATED CIRCUIT ENGINEERING CORPORATION

1. BACKGROUND

1. BACKGROUND

Under NASA Contract # NAS8-38812 ICE prepared the following material regarding safety of NASA's in-house microelectronic's facility. This is the FED operation which is located in Huntsville, Alabama. The following material represents the various studies, reports, and recommendations which were requested during the course of the contract.

2. INDUSTRY HEALTH STANDARDS

OCCUPATIONAL HEALTH STANDARDS

I. EMPLOYEE HEALTH MONITORING

Employees with a potential exposure to chemicals or compounds which pose a potential threat to their physical health and well-being shall be physically monitored on a regularly scheduled basis.

This program will be administered by the Safety Department and carried out by the Medical Department.

II. MONITORING OF THE WORK ENVIRONMENT

The work environment where these substances are used shall be monitored on a regularly scheduled basis as required by government regulations or by our own schedules whichever are most stringent. Recordkeeping requirements as required by government regulations is the responsibility of the Safety Department.

III. CHEMICALS AND/OR COMPOUNDS WHICH POSE A POTENTIAL THREAT TO PHYSICAL HEALTH AND WELL-BEING

A. Human Carcinogens

1. Arsenic Trioxide
2. Asbestos, All Forms
3. Bis (Chloromethyl) Ether
4. Chromite Ore
5. Nickel Sulfide Roasting Fume & Dust
6. Particulate Polycyclic Aromatic Hydrocarbons
7. 4-Aminodiphenyl (P-Xenylamine)
8. Benzidine
9. Beta-Naphthylamine
10. 4-Nitrodiphenyl
11. Vinyl Chloride

B. Suspected Human Carcinogens

1. Antimony Trioxide
2. Benzene
3. Benz (A) Pyrene
4. Beryllium
5. Cadmium Oxide
6. Chloroform
7. Chromates of Lead and Zinc
8. 3,3' - Dichlorobenzidine
9. Dimethylcarbaryl Chloride

III. (Continued)

B. Suspected Human Carcinogens

10. 1,1 - Dimethyl Hydrazine
11. Dimethyl Sulfate
12. Epichlorhydrin
13. Hexamethyl Phosphoramide
14. Hydrazine
15. MQCA
16. 4,4' - Methylene Dianiline
17. Monomethyl Hydrazine
18. Nitrosamines
19. Propane Sulfone
20. Beta-Propiolactone
21. Thallium
22. Vinyl Cyclohexene Dioxide

C. Heavy Metals

1. Lead
2. Boron Compounds
3. Phosphorus Compounds
4. Chromates
5. Mercury
6. Nickel Compounds

IV. NOTIFICATION OF USE

All operating departments, areas, laboratories, engineering areas, etc. that use or contemplate using any of the substances listed in III above, must report such use or contemplated use to their respective safety departments annually. Discontinued use must also be reported when it occurs. Using departments shall request an Annual Safety Permit in the form of an equipment label on a calendar year basis.

V. APPROVAL TO PURCHASE

Except for process chemicals approved for routine use and purchased in bulk, all other purchases of the substances listed in III above, shall be approved by the respective safety department to assure proper practice before purchase and delivery.

INTEGRATED CIRCUIT ENGINEERING CORPORATION

OPERATOR MEDICAL CHECKS*

<u>MATERIAL</u>	<u>C O M P A N I E S</u>			
	<u>NATIONAL</u>	<u>INTERSIL</u>	<u>A</u>	<u>B</u>
Arsenic Trioxide	30 days	45 days	90 days	60 days
TCE (111 Trichloroethane)	30 days	45 days	-	60 days
Acetone	30 days	45 days	-	60 days
Diborane	30 days	45 days	-	-
Phosphene	30 days	45 days	-	-
Arsene	30 days	45 days	-	-

* Blood Test and Exam

3. FACILITY EMISSION CONTROL REQUIREMENTS

FED
EMISSION CONTROL REQUIREMENTS

A SPECIAL TASK STUDY
FOR
NASA

By
INTEGRATED CIRCUIT ENGINEERING CORPORATION
SCOTTSDALE, ARIZONA
JUNE 1978

FED EMISSION CONTROL
REQUIREMENTS

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1.
BACKGROUND

1. BACKGROUND

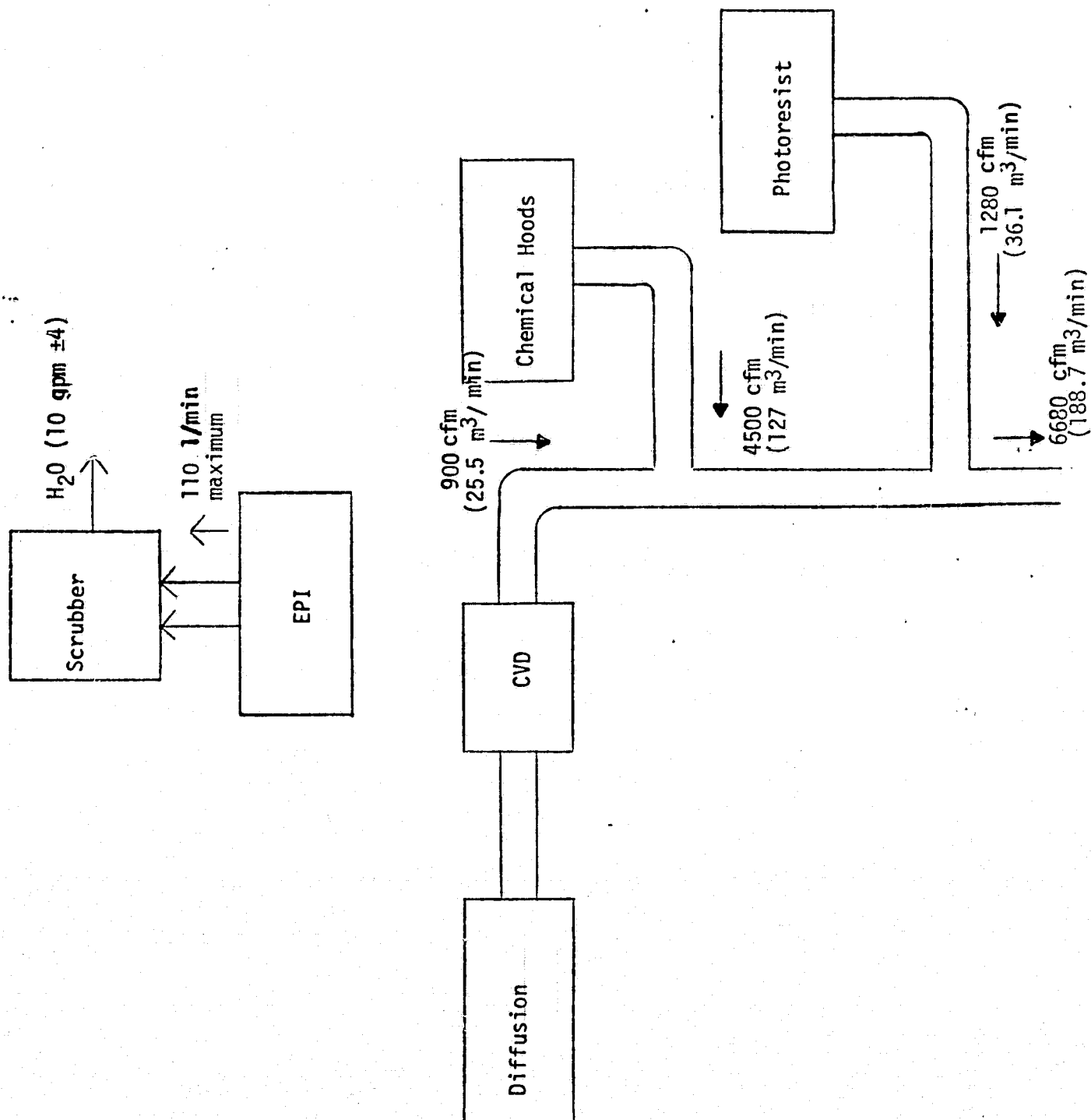
The following is an initial report on the emission control requirements for the FED operation, which is located at the NASA facility in Huntsville, Alabama. This work was requested by Mr. Ralph Grubb, and is part of Contract No. NAS8-32812. This study and initial report involves the determination of the safety of the present exhaust gas system of the laboratory, and other equipment would be required to meet acceptable industry and OSHA standards. The following report presents the detailed calculations and ICE's recommendations.

To provide more flexibility in the use of the data, the laboratory was divided into four sections, as shown on the attached chart. Calculations for each section were made individually, in addition calculations are made on the combined results to allow for any unique chemical combinations which might occur during exhaust gas mixing. These areas are as follows:

- (a) Diffusion and CVD
- (b) Etch Stations (Chemical Hoods)
- (c) Photoresist
- (d) Epi

The specific assumptions and backgrounds are given under each section.

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2.
SUMMARY

2. SUMMARY

Based upon the chemical and air-flow data, as supplied by NASA, the present exhaust system, which includes the CVD/diffusion, etch stations, and photoresist operations, will exceed OSHA limits for three different materials and be near the OSHA limit for one other, as shown in Figure 2.

Calculations were based both on normal operations and worst case conditions. As shown in Figure 3, under worst case conditions the hydrochloric acid from the CVD/diffusion area will exceed OSHA limits. Under normal operations the acetone and trichlorethylene from the etch station area will exceed OSHA limits. Thus, ICE would recommend the insulation of a gas scrubber to handle this exhaust system. This facility would then be compatible, with semiconductor practices with regard to safety and pollution control.

When the individual operations are considered with their normal exhaust gas flow, other chemicals also will exceed the OSHA limits in those branch lines. Figure 4 indicates that the exhaust, directly from the CVD/diffusion area at 900 cubic feet per minute ($25\text{m}^3/\text{min}$), will exceed OSHA limits for hydrogen chloride, ammonium chloride, and diborane. It should be noted however, that this will be further diluted in the total exhaust system, and the ammonium chloride and diborane will fall within safe limits. Figure 5 shows that the exhaust directly from the etch facility also exceeds OSHA limits for acetone and TCE. The exhaust from the photoresist area of approximately 1280 cubic feet per minute ($36\text{m}^3/\text{min}$), is sufficient and none of the chemicals will exceed OSHA limits.

Figure 6 is a summary of the total combined reacted exhaust from the system.

The epitaxial area was treated separately because it did have a separate exhaust system. Figure 7 shows that six chemicals in the epitaxial area will exceed OSHA limits. These are ammonia, hydrogen chloride, nitrous oxide, diborane, phosphine, and arsine. This confirms the requirement of the scrubber for that system which has already been ordered and is now being installed. Additional studies also show that the epitaxial exhaust will need a hydrogen burn-off.

FIGURE 2

CRITICAL MATERIALS

1. OVER OSHA LIMITS
 - (A) HYDROCHLORIC ACID
 - (B) ACETONE
 - (C) TRICHLORETHYLENE
2. NEAR OSHA LIMITS
 - (A) SULFURIC ACID

3

ASSUMPTIONS

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FIGURE 3

CRITICAL AREAS

TOTAL FACILITY (ETCH, PHOTORESIST, CVD/DIFFUSION)

EMISSIONS, mg/m^3			
<u>MATERIAL</u>	<u>NORMAL OPERATION</u>	<u>WORSE CASE OPERATION</u>	<u>OSHA LIMITS</u>
1. HYDROCHLORIC ACID	3.89	9.07	7
2. ACETONE	2953	-	2400
3. TRICHTHLORETHYLENE	2338	-	535

FIGURE 4

CRITICAL AREAS

CVD/DIFFUSION

EMISSIONS, mg/m^3

<u>MATERIAL</u>	<u>NORMAL OUTPUT</u>	<u>WORSE CASE* OUTPUT</u>	<u>OSHA LIMITS</u>
1. HYDROGEN CHLORIDE	28.8	67.2	7
2. AMMONIUM CHLORIDE	7.53	15.1	5
3. DIBORANE	0.101	0.202	0.1

FIGURE 5

CRITICAL AREAS
ETCH FACILITY

<u>MATERIAL</u>	<u>EMISSIONS, mg/m^3</u>	
	<u>NORMAL OPERATION</u>	<u>OSHA LIMITS</u>
1. ACETONE	2953	2400
2. TCE	2338	535

Figure 6

COMBINED TOTAL EMISSIONS FROM
ETCH STATIONS, DIFFUSION AND CVD STATIONS, AND PHOTORESIST STATIONS

HYDROFLUORIC ACID HF	HYDROCHLORIC ACID HCl	NITRIC ACID HNO ₃	SULFURIC ACID H ₂ SO ₄	PHOSPHORIC ACID H ₃ PO ₄	ACETIC ACID CH ₃ COOH	ACETONE	TRICHLOR ETHYLENE	PROPANOL	XYLENE	STANDARD SOLVENT	BUTYL ACETATE	AMMONIA NH ₃	AMMONIUM CHLORIDE NH ₄ Cl	NITROUS OXIDE N ₂ O	DIEOXANE B ₂ H ₆	PHOSPHINE PH ₃
----------------------------	-----------------------------	------------------------------------	--	--	--	---------	----------------------	----------	--------	---------------------	------------------	----------------------------	--	--------------------------------------	---	------------------------------

ETCH FACILITY

Normal Case

ppm
mg/m³
g/day

0.89
0.79
145

0.002
0.004
.732

0.510
1.74
318

0.056
0.785
144

0.009
0.037
6.77

2.8
7.6
1390

1139
2953
540,000

399
2338
428,000

45.4
122
22,300

CVD AND DIFFUSION FACILITY

Normal Case

ppm
mg/m³
g/day

0.424
0.323
87.8

0.425
1.02
276

0.529
1.04
282

0.019
0.013
140

0.011
0.016
173

Worst Case

ppm
mg/m³
g/day

5.56
8.07
2459

0.848
2.04
554

1.05
2.08
564

0.021
0.026
279

0.021
0.032
347

PHOTORESIST FACILITY

Normal Case

ppm
mg/m³
g/day

0.056
0.361
97.9

0.044
0.186
50.6

0.020
0.134
36.3

31
130

14.8
92.2

Worst Case

ppm
mg/m³

TOTAL FACILITY EXHAUST

Normal Case

ppm
mg/m³
g/day

0.69
0.79
145

2.39
3.89
1054

0.510
1.74
318

0.056
0.785
144

0.009
0.037
6.77

2.8
7.6
1390

1139
2953
540,000

399
2338
428,000

45.4
122
22,300

0.056
0.361
97.9

0.044
0.186
50.6

0.020
0.134
36.3

0.424
0.323
87.8

0.425
1.02
276

0.529
1.04
282

0.019
0.013
140

0.011
0.016
173

Worst Case

ppm
mg/m³
g/day

5.56
9.07
2459

0.848
2.04
554

1.05
2.08
564

0.021
0.026
279

0.021
0.032
347

OSHA LIMITS

ppm
mg/m³

3
2

5
7

2
5

1
1

1
1

10
25

1000
2400

100
535

200
500

100
435

200
1150

150
710

50
35

5(Dust)

25(Tent) 0.1
0.1

0.3
0.4

Problem Areas

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FIGURE 7

CRITICAL AREAS
EPITAXY OPERATIONS

MATERIAL	EMISSIONS, mg/m^3	
	WORSE CASE OPERATION	OSHA LIMITS
1. AMMONIA	500,000	50
2. HYDROGEN CHLORIDE	750,000	5
3. NITROUS OXIDE	25,300	25
4. DIBORANE	1.29	.1
5. PHOSPHINE	1.29	.3
6. ARSINE	1.29	.05

3. ASSUMPTIONS

The conclusions and recommendations of this report are based upon raw data supplied by NASA with regard to typical and maximum gas flows on normal equipment usage. This data has not been confirmed or check by ICE. ICE's calculations are based upon both typical and worse case conditions. Detailed assumptions as to gas flow and usage are given in the individual sections.

4

DIFFUSION

AND

C V D

4. CVD AND DIFFUSION

Because of the venting arrangements these two operations were considered as one group, in terms of exhaust gas requirements. Included in this group are the diffusion furnaces consisting of six tubes, and the CVD system consisting of two chambers. The basic assumptions are given in Figure 8. It is assumed that the total vent flow from this area is 25.5 cubic meters per minute. Normal operation assumes that one tube is operating for each type of dopant. Worst case conditions assumes two tubes. Normal conditions for HCl cleaning assumes two tubes. The worst case condition assumes all six tubes. For the CVD operation the normal operation assumes that one chamber is operating. The worst case condition assumes both chambers. The various chemicals used for both systems is listed in the following calculations. Figure 9 is the summary of the chemical outputs from this particular system. It should be noted that OSHA limits are exceeded at the output of this system for hydrogen chloride, ammonium chloride, and diborane, however the OSHA limits are exceeded only for hydrogen chloride when this system is fully diluted at the exhaust output.

During the inspection of this facility it was noted that the output of the CVD reactor was not protected with ventilation or a hood. If the glass chamber would break, during the reactor operation the chemicals could quickly disperse into the room. It is, thus, recommended that that end of the CVD reactor be included in a vent or hood arrangement.

FIGURE 8

DIFFUSION OPERATION ASSUMPTIONS

2 Tubes Phosphine, 1% PH_3 in Argon (Nitrogen)

87cc/min Diluted with 11.2 l/min of Inert Gas

2 Tubes Diborane, 0.1% B_2H_6 in argon (Nitrogen)

87cc/Min Diluted with 5 l/min of Inert Gas

2 Oxidation Tubes

HCl Gas for Tube Cleaning - 15% in O_2 99.999% HCl

HCl Gas Flow is 500 cc/min

Assume Normal 2, maximum of 6 tubes cleaned at one time.

Total Vent Flow 25.5 m^3/min - No Dilution with CVD

Average Clean 300cc/min

Final Dilution with Total Exhaust

$$\frac{25.5 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .135 \text{ Diffusion and CVD Dilution Factor}$$

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CVD AND DIFFUSION OPERATION EMISSIONS

	CVD OPERATION	DIFFUSION OPERATION	GROSS UNREACTED TOTAL OUTPUT		NET COMBINED OUTPUT MINIMUM REACTED MAXIMUM		NET OUTPUT WITH TOTAL EXHAUST DILUTION MINIMUM REACTED MAXIMUM		OSHA LIMITS	PROBLEM AREAS		
			RUN	CLEAN	RUN	CLEAN	RUN	CLEAN				
AMMONIA (NH ₃)												
ppm, Normal Case	3.14		3.14	CLEAN	3.14	0	3.14	.424	0	.424	50	
ppm, Worst Case	6.28		6.28	17.7	6.28	0	6.28	.848	0	.848	50	
mg/m ³ , Normal Case	2.39		2.39	5.1	2.39	0	2.39	.323	0	.323	35	
mg/m ³ , Worst Case	4.78		4.78	10.2	4.78	0	4.78	.645	0	.645	35	
g/day, Normal Case	87.8		87.8	187	87.8	0	176	176	0	176		
g/day, Worst Case	176		176	374								
HYDROGEN CHLORIDE												
ppm, Normal Case	3.14	5.89	3.14	17.7	3.14	2.72	3.14	.424	.367	2.39	5	*
ppm, Worst Case	6.28	17.7	6.28	41.2	6.28	11.3	6.28	.848	1.53	5.56	5	*
mg/m ³ , Normal Case	5.1	9.59	5.1	23.8	5.10	4.44	5.10	.689	.599	3.89	7	*
mg/m ³ , Worst Case	10.2	28.8	10.2	67.2	10.2	18.4	10.2	1.38	2.48	9.09		
g/day, Normal Case	187	351	187	1054	187	163	187	187	163	1054		
g/day, Worst Case	374	1053	374	2459	374	676	374	374	676	2459		
AMMONIUM CHLORIDE												
ppm, Normal Case			0		0	3.15			.425	.425		
ppm, Worst Case			0		0	6.32			.853	.853		
mg/m ³ , Normal Case			0		0	7.53			1.02	1.02	5(Dust)	
mg/m ³ , Worst Case			0		0	15.1			2.04	2.04	5(Dust)	
g/day, Normal Case			0		0	276			276	276		
g/day, Worst Case			0		0	554			554	554		
NITROUS OXIDE (N ₂ O)												
ppm, Normal Case	3.92		3.92				3.92		.529	.529	25(Tent)	
ppm, Worst Case	7.85		7.85				7.85		1.06	1.06	25(Tent)	
mg/m ³ , Normal Case	7.7		7.7				7.7		1.04	1.04		
mg/m ³ , Worst Case	15.4		15.4				15.4		2.08	2.08		
g/day, Normal Case	282		282				282		282	282		
g/day, Worst Case	564		564				564		564	564		
DIBORANE (B ₂ H ₆)												
ppm, Normal Case	.078	.053	.031				.081		.011	.011	.1	
ppm, Worst Case	.156	.007	.163				.163		.021	.021	.1	
mg/m ³ , Normal Case	.097	.004	.101				.101		.013	.013	.1	
mg/m ³ , Worst Case	.194	.008	.202				.202		.026	.026	.1	
g/day, Normal Case	140	.14	140				140		140	140		
g/day, Worst Case	279	.28	279				279		279	279		
PHOSPHINE (PH ₃)												
ppm, Normal Case	.078	.034	.112				.112		.011	.011	.3	
ppm, Worst Case	.156	.068	.224				.224		.021	.021	.3	
mg/m ³ , Normal Case	.119	.052	.171				.171		.016	.016	.4	
mg/m ³ , Worst Case	.238	.104	.342				.342		.032	.032	.4	
g/day, Normal Case	.171	1.9	173				173		173	173		
g/day, Worst Case	343	3.8	347				347		347	347		

DIFFUSION OPERATION CALCULATIONS

PHOSPHINE DOPANT GAS

Assume 1 tube with 1% PH_3 (in argon or nitrogen) at 87 cc/min diluted with 11.2 l/min of (argon or nitrogen). Assume worst case of 2 tubes run continuously for 24 hr/day with no dilute gas:

$$87 \text{ cc/min} \times .01 = .87 \text{ cc/min } \text{PH}_3$$

$$\frac{.00087 \text{ l}}{22.4 \text{ l/mol}} \times 34 \text{ g/mol} = .00132 \text{ g/min } \text{PH}_3 = 1.32 \text{ mg/min } \text{PH}_3$$

One Tube in Operation

$$\frac{1.32 \text{ mg/min}}{900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = .052 \text{ mg/m}^3 \text{ } \text{PH}_3 \text{ in Total Exhaust}$$

Two Tubes in Operation

$$.052 \times 2 = .104 \text{ mg/m}^3 \text{ } \text{PH}_3 \text{ in Total Exhaust}$$

OSHA Limit is 0.4 mg/m^3

Total Daily Maximum Emission:

$$1.32 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 1.9 \text{ g/day } \text{PH}_3 \text{ One Tube}$$

$$\text{Two Tubes} = 3.8 \text{ g/day } \text{PH}_3$$

With Total Exhaust Dilution

Normal Case

$$.052 \text{ mg/m}^3 \times .135 = .007 \text{ mg/m}^3 \text{ } \text{PH}_3$$

Worst Case

$$.104 \text{ mg/m}^3 \times .135 = .014 \text{ mg/m}^3 \text{ } \text{PH}_3$$

DIFFUSION OPERATION

PHOSPHINE GAS

Assume normal operations of 1 tube and maximum of 2 tubes operates at one time with 87cc/min of 1% PH₃ (in argon or nitrogen) diluted with 11.2 l/M of argon or nitrogen

Normal Case

$$87\text{cc/min} \times .01 = .87 \text{ cc/min PH}_3$$

$$\frac{.87 \text{ cc/min}}{(900 \text{ CFM} + 11.2 \text{ l/M}) \times 28317 \text{ cc/cf}} = .034 \text{ ppm PH}_3 \text{ Gas}$$

$$\text{Worst Case of 2 Tubes} = .068 \text{ ppm PH}_3 \text{ Gas}$$

OSHA Limit is 0.3 ppm

With Total Exhaust Dilution

Normal Case

$$.034 \text{ ppm} \times .135 = .005 \text{ ppm PH}_3$$

Worst Case

$$.068 \text{ ppm} \times .135 = .009 \text{ ppm PH}_3$$

DIFFUSION OPERATION

DIBORANE DOPANT GAS

Assume 1 tube with 0.1% B₂H₆ (in argon or nitrogen) at 87 cc/min
5 l/min of argon or nitrogen. Assume worst case of 2 tubes run
continuously for 24 hr/day with no dilute gas:

$$87 \text{ cc/min} \times .001 = .087 \text{ cc/min B}_2\text{H}_6$$

$$\frac{.000087 \text{ l}}{22.4 \text{ l/mol}} \times 27.67 \text{ g/mol} = .000010 \text{ g/min B}_2\text{H}_6 = .10 \text{ mg/min}$$

One Tube

$$\frac{.10 \text{ mg/min}}{900 \text{ CFM} \times .0283 \text{ m}^3/\text{cf}} = .0039 \text{ mg/m}^3 \text{ B}_2\text{H}_6$$

Two Tubes

$$.0039 \text{ mg/m}^3 \times 2 = .0078 \text{ mg/m}^3 \text{ B}_2\text{H}_6 \text{ in Total Exhaust}$$

OSHA Limit is 0.1 mg/m³

Total Daily Maximum Emission

$$.10 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 0.14 \text{ g/day B}_2\text{H}_6$$

$$\text{Two Tubes} = 0.28 \text{ g/day B}_2\text{H}_6$$

With Total Exhaust Dilution

Normal Case

$$.0039 \text{ mg/m}^3 \times .135 = .0005 \text{ mg/m}^3 \text{ B}_2\text{H}_6$$

Worst Case

$$.0078 \text{ mg/m}^3 \times .135 = .0010 \text{ mg/m}^3 \text{ B}_2\text{H}_6$$

DIFFUSION OPERATION

DIBORANE GAS

Assume normal operation of 1 tube and maximum of 2 tubes operated at one time with 87cc/min of 0.1% B₂H₆ (in argon or nitrogen) diluted with 5 l/min of argon or nitrogen.

Normal Case

$$87\text{cc/min} \times .001 = .087 \text{ cc/min B}_2\text{H}_6$$

$$\frac{.087 \text{ cc/min}}{(900 \text{ CFM} + 5 \text{ l/M}) \times 28317 \text{ cc/cf}} = .0034 \text{ ppm B}_2\text{H}_6$$

Worst Case of 2 Tubes = .0068 ppm B₂H₆

OSHA Limit is 0.1 ppm

With Total Exhaust Dilution

Normal Case

$$.0034 \text{ ppm} \times .135 = .0005 \text{ ppm B}_2\text{H}_6$$

Worst Case

$$.0068 \text{ ppm} \times .135 = .0009 \text{ ppm B}_2\text{H}_6$$

DIFFUSION OPERATION

HCl TUBE CLEANING

Assume normal operations of 2 tubes or maximum of 6 tubes cleaned at one time using 15% HCl in O₂ at gas flow of 500 cc/min/tube for 24 hr/day

Two Tubes (Normal)

$$500 \text{ cc/min} \times 2 \times .15 = 150 \text{ cc/min HCl}$$

$$\frac{.150 \text{ l}}{22.4 \text{ l/mol}} \times 36.46 \text{ g/mol} = .244 \text{ g/min} = 244 \text{ mg/min HCl}$$

$$\frac{244 \text{ mg/min}}{900 \text{ CFM} \times .0283} = 9.59 \text{ mg/m}^3 \text{ HCl}$$

OSHA Limit is 7 mg/m³

Total Daily Maximum Emission

$$244 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 351 \text{ g/day HCl}$$

Six Tubes (Maximum)

$$9.59 \text{ mg/m}^3 \times 3 = 28.8 \text{ mg/m}^3 \text{ HCl}$$

OSHA Limit is 7 mg/m³ HCl

Total Daily Maximum Emission

$$351 \text{ g/day} \times 3 = 1.053 \text{ kg/day}$$

With Total Exhaust Dilution

Normal Case

$$9.59 \text{ mg/m}^3 \times .135 = 1.29 \text{ mg/m}^3 \text{ HCl}$$

Worst Case

$$28.8 \text{ mg/m}^3 \times .135 = 3.88 \text{ mg/m}^3 \text{ HCl}$$

DIFFUSION OPERATION

HC1 TUBE CLEANING

Assume normal operations of 2 tubes or maximum of 6 tubes cleaned at one time using gas flow of 500 cc/min/tube of 15% HC1 in O₂

Normal Case 2 Tubes

$$500\text{cc} \times 2 \times .15 = 150\text{cc/min HC1}$$

$$\frac{150 \text{ cc/min}}{900 \text{ cfm} \times 28317 \frac{\text{cc}}{\text{cf}}} = 5.89 \text{ ppm HC1}$$

Worst Case 6 Tubes = 17.7 ppm HC1 Gas

OSHA Limit is 5 ppm

With Total Exhaust Dilution

Normal Case

$$5.89 \text{ ppm} \times .135 = .796 \text{ ppm HC1}$$

Worst Case

$$17.66 \text{ ppm} \times .135 = 1.59 \text{ ppm HC1}$$

C V D OPERATION

Ammonia, NH_3

Flow: 80 cc/min

Concentration: 100%

HCl Hydrogen Chloride

Flow: 300 cc/min in clean cycle

Concentration: 99.99%

Dichlorosilane, SiH_2Cl_2

Flow: 40 cc/min Vapor Product

Concentration: 100%

Nitrous Oxide, N_2O

Flow: 100 cc/min

Concentration: 100 %

Diborane, B_2H_6

Flow: 100 cc/min

Concentration: 10% in Argon

Phosphine, PH_3

Flow: 20 cc/min

Concentration: 10% in Argon

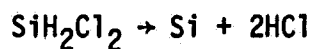
CVD Vent Flow = 25.5 m^3/min Final Dilution with Total Exhaust

$$\frac{25.5 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .135$$

C V D OPERATION

DICHLOROSILANE GAS

Assume 40 cc/min of 100% SiH_2Cl_2 in one chamber.



40 cc/min $\text{SiH}_2\text{Cl}_2 \rightarrow 80$ cc/min HCl

$$\frac{80 \text{ cc/min}}{900 \text{ cfm} \times 28317 \frac{\text{cc}}{\text{cf}}} = 3.14 \text{ ppm HCl}$$

Worst Case 2 Chambers = 6.28 ppm HCl

OSHA Limit is 5 ppm

With Total Exhaust Dilution

Normal Case

$$3.14 \text{ ppm} \times .135 = .424 \text{ ppm HCl}$$

Worst Case

$$6.28 \text{ ppm} \times .135 = .848 \text{ ppm HCl}$$

PHOSPHINE GAS

Assume 20 cc/min of 10% PH_3 in argon in one chamber

$$20 \text{ cc/min} \times .1 = 2 \text{ cc/min PH}_3$$

$$\frac{2 \text{ cc/min}}{900 \text{ cfm} \times 28317 \frac{\text{cc}}{\text{cf}}} = .078 \text{ ppm PH}_3$$

Worst Case 2 Chambers = .156 ppm PH_3

OSHA Limit is 0.3 ppm

With Total Exhaust Dilution

Normal Case

$$.078 \text{ ppm} \times .135 = .011 \text{ ppm PH}_3$$

Worst Case

$$.156 \text{ ppm} \times .135 = .021 \text{ ppm PH}_3$$

C V D OPERATION

PHOSPHINE GAS

Assume 20 cc/min of 10% PH₃ in argon in one chamber.

$$20 \text{ cc/min} \times .1 = 2 \text{ cc/min PH}_3$$

$$\frac{.002 \text{ l/min}}{22.4 \text{ l/mol}} \times 34 \text{ g/mol} = .00304 \text{ g/min PH}_3 = 3.04 \text{ mg/min PH}_3$$

One Chamber Operation

$$\frac{3.04 \text{ mg/min}}{900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = .119 \text{ mg/m}^3 \text{ PH}_3 \text{ in Total Exhaust}$$

Two Chamber Operation

$$.119 \text{ mg/m}^3 \times 2 = .238 \text{ mg/m}^3 \text{ PH}_3$$

$$2 \text{ Chamber} = 342.7 \text{ mg/day}$$

With Total Exhaust Dilution

Normal Case

$$.119 \text{ mg/m}^3 \times .135 = .016 \text{ mg/m}^3 \text{ PH}_3$$

Worst Case

$$.238 \text{ mg/m}^3 \times .135 = .032 \text{ mg/m}^3 \text{ PH}_3$$

C V D OPERATION

DIBORANE GAS

Assume 20 cc/min of 10% B₂H₆ in argon in one chamber.

$$20 \text{ cc/min} \times .1 = 2 \text{ cc/min B}_2\text{H}_6$$

$$\frac{2 \text{ cc/min}}{900 \text{ cfm} \times 28317 \frac{\text{cc}}{\text{cf}}} = .078 \text{ ppm B}_2\text{H}_6 \text{ Gas}$$

$$\text{Worst Case } 2 \text{ Chambers} = .156 \text{ ppm B}_2\text{H}_6$$

OSHA Limit is .10 ppm

With Total Exhaust Dilution

Normal Case

$$.078 \text{ ppm} \times .135 = .0105 \text{ ppm B}_2\text{H}_6$$

Worst Case

$$.156 \text{ ppm} \times .135 = .021 \text{ ppm B}_2\text{H}_6$$

NITROUS OXIDE GAS

Assume 100 cc/min of 100 N₂O gas in one chamber.

$$\frac{100}{900 \text{ cfm} \times 28317} = 3.92 \text{ ppm N}_2\text{O}$$

$$\text{Worst Case } 2 \text{ Chambers} = 7.85 \text{ ppm}$$

OSHA Limit is 25 ppm (Proposed)

With Total Exhaust Dilution

Normal Case

$$3.92 \text{ ppm} \times .135 = .529 \text{ ppm N}_2\text{O}$$

Worst Case

$$7.85 \text{ ppm} \times .135 = 1.06 \text{ ppm N}_2\text{O}$$

C V D OPERATION

AMMONIA GAS

Assume 80 cc/min of 100% NH₃ gas in one chamber.

$$\frac{80 \text{ cc/min}}{900 \text{ cfm} \times 28317 \frac{\text{cc}}{\text{cf}}} = 3.14 \text{ ppm NH}_3$$

Worst Case 2 Chambers = 6.28 ppm NH₃

OSHA Limit is 50 ppm

With Total Exhaust Dilution

Normal Case

$$11.77 \text{ ppm} \times .135 = 1.59 \text{ ppm HCl}$$

Worst Case

$$23.54 \text{ ppm} \times .135 = 3.18 \text{ ppm HCl}$$

HYDROGEN CHLORIDE GAS

Assume 300 cc/min of 99.99% HCl Gas in one Chamber.

$$\frac{300 \text{ cc/min}}{900 \text{ cfm} \times 28317 \frac{\text{cc}}{\text{cf}}} = 11.8 \text{ ppm HCl}$$

Worst Case 2 Chambers = 23.5 ppm HCl

OSHA Limit is 5 ppm

With Total Exhaust Dilution

Normal Case

$$3.14 \text{ ppm} \times .135 = .424 \text{ ppm NH}_3$$

Worst Case

$$6.28 \text{ ppm} \times .135 = .848 \text{ ppm NH}_3$$

C V D OPERATION

N₂O GAS

Assume 100 cc/min of 100% N₂O gas in one chamber.

$$\frac{.100 \text{ l/min}}{22.4 \text{ l/mol}} \times 44.01 \text{ g/mol} = .196 \text{ g/min} = 196 \text{ mg/min N}_2\text{O}$$

$$\frac{196 \text{ mg/min}}{900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 7.7 \text{ mg/m}^3 \text{ N}_2\text{O}$$

Worst Case 2 chambers 15.4 mg/m³

OSHA Limit is 25 PPM (Proposed)

Total Daily Emission with Continuous Flow.

$$196 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 282 \text{ g/day}$$

Worst Case 2 chambers 564 g/day

With Total Exhaust Dilution

Normal Case

$$7.7 \text{ mg/m}^3 \times .135 = 1.04 \text{ mg/m}^3 \text{ N}_2\text{O}$$

Worst Case

$$15.4 \text{ mg/m}^3 \times .135 = 2.08 \text{ mg/m}^3 \text{ N}_2\text{O}$$

C V D OPERATION

DIBORANE GAS

Assume 20 cc/min of 10% B₂H₆ in argon in one chamber.

$$20 \text{ cc/min} \times .1 = 2 \text{ cc/min B}_2\text{H}_6$$

One Chamber Operation

$$\frac{.002 \text{ l/min}}{22.4 \text{ l/mol}} \times 27.67 \text{ g/mol} = .00247 \text{ g/min B}_2\text{H}_6 = 2.47 \text{ mg/min B}_2\text{H}_6$$

$$\frac{2.47 \text{ mg/min}}{900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = .097 \text{ mg/m}^3 \text{ B}_2\text{H}_6 \text{ in Total Exhaust}$$

Two Chamber Operation

$$.097 \text{ mg/m}^3 \times 2 = .194 \text{ mg/m}^3 \text{ B}_2\text{H}_6$$

Total Daily Maximum Emission

$$.097 \text{ mg/m}^3 \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 139.7 \text{ mg/day}$$

$$2 \text{ Chamber} = 279.4 \text{ mg/day}$$

With Total Exhaust Dilution

Normal Case

$$.097 \text{ mg/m}^3 \times .135 = .013 \text{ mg/m}^3 \text{ B}_2\text{H}_6$$

Worst Case

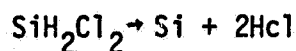
$$.194 \text{ mg/m}^3 \times .135 = .026 \text{ mg/m}^3 \text{ B}_2\text{H}_6$$

C V D OPERATION

DICHLOROSILANE GAS

Assume 40 cc/min flow of 100% gas.

$$\frac{.040 \text{ l/min}}{22.4 \text{ l/mol}} \times 101.01 \text{ g/mol} = .180 \text{ g/min} = 180 \text{ mg/min SiH}_2\text{Cl}_2$$



$$180 \text{ mg/min} \times \frac{72.92 \text{ g}}{101.01 \text{ g}} = 129.9 \text{ mg/min HCl}$$

$$40 \text{ cc/min SiH}_2\text{Cl}_2 \rightarrow 80 \text{ cc/min HCl}$$

In One Chamber

$$\frac{129.9 \text{ mg/min}}{900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 5.1 \text{ mg/m}^3 \text{ HCl}$$

$$\text{Worst Case} = 2 \text{ chambers} = 10.2 \text{ mg/m}^3 \text{ of HCl}$$

$$\text{OSHA Limit is } 7 \text{ mg/m}^3$$

Total Daily Emission with Continuous Flow

$$129.9 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 187 \text{ g/day}$$

$$\text{Worst Case} = 2 \text{ chambers} = 374 \text{ g/day HCl}$$

With Total Exhaust Dilution

Normal Case

$$5.1 \text{ mg/m}^3 \times .135 = .689 \text{ mg/m}^3 \text{ HCl}$$

Worst Case

$$10.2 \text{ mg/m}^3 \times .135 = 1.38 \text{ mg/m}^3 \text{ HCl}$$

C V D OPERATION

NH₃ Gas

Assume 80 cc/min of 100% NH₃ Gas.

$$\frac{.080 \text{ l/min}}{22.4 \text{ l/mol}} \times 17.03 \text{ g/mol} = .061 \text{ g/min} = 61 \text{ mg/min NH}_3$$

In One Chamber

$$\frac{61 \text{ mg/min}}{900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 2.39 \text{ mg/m}^3 \text{ NH}_3$$

$$\text{Worst Case} = 2 \text{ Chambers} = 4.78 \text{ mg/m}^3 \text{ NH}_3$$

OSHA Limit is 35 mg/m³

Total Daily Emission with Continuous Flow.

$$61 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 87.8 \text{ g/day}$$

$$\text{Worst Case} = 2 \text{ Chambers} = 175.7 \text{ g/day}$$

With Total Exhaust Dilution

Normal Case

$$2.39 \text{ mg/m}^3 \times .135 = .323 \text{ mg/m}^3 \text{ NH}_3$$

Worst Case

$$4.78 \text{ mg/m}^3 \times .135 = .645 \text{ mg/m}^3 \text{ NH}_3$$

C V D OPERATION

HCl GAS IN CLEAN CYCLE

Assume 300 cc/min of 99.99% HCl Gas.

$$\frac{.300 \text{ l/min}}{22.4 \text{ l/mol}} \times 36.46 \text{ g/mol} = .488 \text{ g} = 488 \text{ mg/min HCl}$$

One Chamber

$$\frac{488 \text{ mg/min}}{900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 19.2 \text{ mg/m}^3 \text{ HCl}$$

$$\text{Worst Case} = 2 \text{ Chambers} = 38.4 \text{ mg/m}^3 \text{ HCl}$$

OSHA Limit is 7 mg/m^3

Total Daily Emission with Continuous Flow.

$$488 \text{ mg/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 703 \text{ g/day}$$

$$\text{Worst Case} = 2 \text{ Chambers} = 1.4 \text{ kg/day}$$

With Total Exhaust Dilution

Normal Case

$$9.2 \text{ mg/m}^3 \times .135 = 1.24 \text{ mg/m}^3 \text{ HCl}$$

Worst Case

$$18.4 \text{ mg/m}^3 \times .135 = 2.48 \text{ mg/m}^3 \text{ HCl}$$

NH₄Cl REACTION PRODUCT



$$\frac{276,000 \text{ mg/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 7.53 \text{ mg/m}^3 \text{ NH}_4\text{Cl}$$

$$\frac{554,000 \text{ mg/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 15.1 \text{ mg/m}^3 \text{ NH}_4\text{Cl}$$

$$\frac{276 \text{ g/day}}{53.49 \text{ g/mol}} \times 22.4 \text{ l/mol} = 115.6 \text{ l/day NH}_4\text{Cl}$$

$$\frac{115,600 \text{ cc/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/cf}} = 3.15 \text{ ppm NH}_4\text{Cl}$$

$$\frac{554 \text{ g/day}}{53.49 \text{ g/mol}} \times 22.4 \text{ l/mol} = 231.9 \text{ l/day NH}_4\text{Cl}$$

$$\frac{231,000 \text{ cc/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/cf}} = 6.32 \text{ ppm NH}_4\text{Cl}$$

With Total Exhaust Dilution

Normal Case

$$7.53 \text{ mg/m}^3 \times .135 = 1.02 \text{ mg/m}^3 \text{ NH}_4\text{Cl}$$

$$3.15 \text{ ppm} \times .135 = .425 \text{ ppm NH}_4\text{Cl}$$

Worst Case

$$15.1 \text{ mg/m}^3 \times .135 = 2.04 \text{ mg/m}^3 \text{ NH}_4\text{Cl}$$

$$6.32 \text{ ppm} \times .135 = .853 \text{ ppm NH}_4\text{Cl}$$

COMBINED EXHAUST FROM DIFFUSION AND CVD

NORMAL CLEAN CASE

$$\frac{87.8 \text{ g} \times 36.46 \text{ g}}{17.03} = 188 \text{ g of HCl Need to react with NH}_3 \text{ available}$$

$$351 \text{ g} - 188 \text{ g} = 163 \text{ g Excess HCl}$$

$$\frac{188 \text{ g} \times 53.49 \text{ g}}{36.46 \text{ g}} = 276 \text{ g NH}_4\text{Cl Produced}$$

WORST CLEAN CASE

$$\frac{176 \times 36.46 \text{ g}}{17.03 \text{ g}} = 377 \text{ g pf HCl Needed}$$

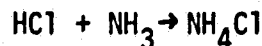
$$1053 \text{ g} - 377 \text{ g} = 676 \text{ g Excess HCl}$$

$$\frac{377 \times 53.49 \text{ g}}{36.46 \text{ g}} = 554 \text{ g NH}_4\text{Cl Produced}$$

5

ETCH
STATIONS

COMBINED EXHAUST FROM DIFFUSION AND CVD

REACTION OF HYDROGEN CHLORIDE AND AMMONIAUNREACTED HCl

Normal Case

$$\frac{163,000 \text{ mg/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 4.44 \text{ mg/m}^3 \text{ HCl}$$

Worst Case

$$\frac{676,000 \text{ mg/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times .0283 \text{ m}^3/\text{cf}} = 18.4 \text{ mg/m}^3 \text{ HCl}$$

$$\frac{163 \text{ g/day}}{36.46 \text{ g/mol}} \times 22.4 \text{ l/mol} = 100 \text{ l/day}$$

$$\frac{100,000 \text{ cc/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/cf}} = 2.72 \text{ ppm HCl}$$

$$\frac{676 \text{ g/day}}{36.46 \text{ g/mol}} \times 22.4 \text{ l/mol} = 415 \text{ l/day}$$

$$\frac{415,000 \text{ cc/day}}{60 \text{ min/hr} \times 24 \text{ hr/day} \times 900 \text{ cfm} \times 28317 \text{ cc/cf}} = 11.3 \text{ ppm HCl}$$

With Total Exhaust Dilution

Normal Case

$$4.44 \text{ mg/m}^3 \times .135 = .599 \text{ mg/m}^3 \text{ HCl}$$

$$2.72 \text{ ppm} \times .135 = .367 \text{ ppm HCl}$$

Worst Case

$$18.4 \text{ mg/m}^3 \times .135 = 2.48 \text{ mg/m}^3 \text{ HCl}$$

$$11.3 \text{ ppm} \times .135 = 1.53 \text{ ppm HCl}$$

5. ETCH STATIONS

The 18 etch stations and the associated vent system was treated as a separate exhaust system, and calculations were made as to maximum emissions of the various chemicals used. Figure 10 shows the basic layout of the etch station and a partial list of the chemicals involved. Figure 11 has a more complete list showing the etch station solution requirements, and the predicted amount of usage. ICE based their calculations upon these values. Figure 12 shows the basic assumptions on vent air flow made for etch stations. Figure 13 is a summary of the total maximum emissions from the etch station facilities. It should be noted that two chemicals, acetone and TCE exceed OSHA limits, and must be treated. The third chemical H_2SO_4 is very close to the OSHA limits and calculations should be made after stations are in operation to determine more accurately the actual values.

It should be noted that it would be possible to substitute for TCE, 111 trichlorethane, which would reduce that particular emission problem. However, the acetone still would exceed the OSHA limits, and scrubbing or some other treatment would still be required.

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FED ETCH STATION

1	2	3	4	5	6	7	8	9	10
Buffer H ₂ O 10:1 HF	D.I. H ₂ O	Jacob Etch	Photo Strip	D.I. H ₂ O	Aluminum Etch H ₃ PO ₄ HNO ₃	Zil Initial Clean H ₂ SO ₄ HNO ₃	D.I. H ₂ O	ACE	ACE

18	17	16	15	14	13	12	11
BOE 50°C	D.I. H ₂ O	PR. Micro Strip	D.I. H ₂ O	PRE Metal 10:1 H ₂ O:HF	H ₃ PO ₄	D.I. H ₂ O	Si Etch Alcohol H ₂ O KOH

FIGURE 10

FACILITY FOR ELECTRONIC DEVELOPMENT

Etch Station Solution Requirements

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Sta. No.	* ≤ 60 Min.	Must Be Covered	Require Mixing Prior To Use	Predicted Amount Of Usage	Required Solution Change Frequency	Used Once & Discarded
1	BOE (RT) H_2O HF NH_4F	X		3-20 times/ process	1000 wafers or 1 month	
18	BOE (50°C)	X		0-5 times/ process	500 wafers or 1 month	
14	10:1 ($\text{H}_2\text{O}:\text{HF}$)	X		1-10 times/ process	1000 wafers or 1 month	
6	Metal Etch Aluminum Etch $\text{H}_3\text{PO}_4\text{-HNO}_3\text{-HAC}$	X	X	1-2 times/ process	200 wafers or 8 hours	
11	Silicon Etch Alcohol $\text{H}_2\text{O KOH}$		X	0-3 times/ process	25 wafers or for each new carrier	X
4	Passivation Etch		X	1-2 times/ process	500 wafers or 2 weeks	X
3	Jacobson's Etch			0-2 times/ process	1 Etch	X
13	Phosphoric Acid		N/A	0-1 times/ process	1 Etch	X
16	Photo Resist Strip (Microstrip)	X	N/A	5-10 times/ process	1 week	
7	Sulfuric-Nitric Acid Solution	X	X	2-3 times/ process	1 day may not be reheated	
9	Acetone	X	N/A	2-5 times/ process	1 day	
10	Trichloroethylene	X	N/A	1-3 times/ process	1 day	

HAC, Acetic Acid

KOH, Potassium Hydroxide

 HNO_3 , Nitric Acid H_3PO_4 , Phosphoric Acid NH_4F , Ammonium Fluoride

Alcohol, Isopropyl Alcohol (Propanol)

FIGURE 11

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Assume Each Etch Station has 8cf Vapor Space (2 x 2 x 2 ft.)

$$8 \text{ cf} = .23 \text{ m}^3$$

$$4500 \text{ cfm} \div 18 \text{ Stations} = 250 \text{ cfm/Station} = 7.08 \text{ m}^3/\text{min/Station}$$

$$\frac{7.08 \text{ m}^3/\text{min}}{.23 \text{ m}^3} = 30.8 \text{ m}^3/\text{m}^3/\text{min} \text{ Space Velocity}$$

Assume only 20% of maximum equilibrium concentration results in vent air moving at 30.8 space velocity.

$$\frac{30.8}{.2} = 154 \text{ Hood Dilution Factor (Space velocity and non-equilibrium)}$$

Add Outside Air

$$\frac{188.7 \text{ m}^3/\text{min}}{127 \text{ m}^3/\text{min}} = 1.5 \text{ Vent Dilution Factor}$$

FIGURE 12

TOTAL MAXIMUM EMISSIONS FROM ETCH FACILITY

	HF	HCl	HNO ₃	H ₂ SO ₄	H ₃ PO ₄	CH ₃ COO	ACETONE	TRICHLOR- ETHYLENE	PROPANOL
	ppm mg/m ³	ppm mg/m ³	ppm mg/m ³	ppm mg/m ³	ppm mg/m ³	ppm mg/m ³	ppm mg/m ³	ppm mg/m ³	ppm mg/m ³
1. 10:1 HF @RT	0.26								
2. DI H ₂ O	0.23								
3. Jacobson Etch @RT		0.0002	0.004	0.002	0.001				
4. P.R. Strip			0.005	0.02	0.082				
5. DI H ₂ O									
6. Aluminum Etch @RT			0.005	0.013	0.003	2.8			
7. H ₂ SO ₄ -HNO ₃ Clean @RT			0.5	1.60	0.014	7.6			
8. DI H ₂ O									
9. Acetone							1139	2338	45.4
10. TCE									122
11. Silicon Etch									
12. DI H ₂ O					0.006	0.025			
13. H ₃ PO ₄ @CRT									
14. 10:1 HF @RT	0.26								
15. DI H ₂ O	0.23								
16. P.R. Strip				0.02	0.082				
17. DI H ₂ O									
13. BCE @ 500C	0.37								
TOTAL FACILITY	0.89	0.0002	0.004	0.056	0.009	2.8	1139	2338	45.4
	0.79		1.743	0.785	0.037	7.6			122
OSHA									
Human Exposure Limits									
(For 8 Hours)	3.0	5.0	2.0	1.0	1.0	10	1000	100	200
	2.0	7.0	5.0	-	-	25	2400	535	500
								350	1900

*Possible Substitute is
1,1,1-Trichlorethane
OSHA Limit

EPA
NO₂ Emissions in
mg/m³/hr
Maximum Hourly
Average 24 hr
(From HNO₃ Etching)

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CALCULATIONS

Etch Station No. 1

10:1 HF = 4.9% HF, Estimated Partial Vapor Pressure @ 20°C ≈ .0006 tor
Equilibrium Concentration

$$\frac{.0006 \text{ tor}}{760 \text{ tor}} \times 20.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 54 \text{ mg/m}^3$$

Maximum Concentration from Station No. 1

$$\frac{54 \text{ mg/m}^3}{154} = .35 \text{ mg/m}^3 \text{ HF}$$

With Vent Dilution

$$\frac{.35 \text{ mg/m}^3}{1.5} = .23 \text{ mg/m}^3 \text{ HF}$$

Etch Station No. 2

No Emission

Etch Station No. 3

5% HCl, Estimated Partial Vapor Pressure @ 20°C ≈ .005 tor

10% HNO₃, Estimated Partial Vapor Pressure @ 20°C ≈ .008 tor

3% H₂SO₄, Estimated Partial Vapor Pressure @ 20°C ≈ .0004 tor

HCl Equilibrium Concentration

$$\frac{.0005 \text{ tor}}{760 \text{ tor}} \times 36.46 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = .97 \text{ mg/m}^3$$

Maximum Concentration from Station No. 3

$$\frac{.97 \text{ mg/m}^3}{154} = .006 \text{ mg/m}^3 \text{ HCl}$$

With Vent Dilution

$$\frac{.006 \text{ mg/m}^3}{1.5} = .004 \text{ mg/m}^3 \text{ HCl}$$

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HNO₃ Equilibrium Concentration

$$\frac{.008 \text{ tor}}{760 \text{ tor}} \times 63.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 29.5 \text{ mg/m}^3$$

Maximum Concentration from Station No. 3

$$\frac{29.5 \text{ mg/m}^3}{154} = .19 \text{ mg/m}^3 \text{ HNO}_3$$

With Vent Dilution

$$\frac{.19 \text{ mg/m}^3}{1.5} = .13 \text{ mg/m}^3 \text{ HNO}_3$$

H₂SO₄ Equilibrium Concentration

$$\frac{.00004 \text{ tor}}{760 \text{ tor}} \times 98.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = .23 \text{ mg/m}^3$$

Maximum Concentration from Station No. 3

$$\frac{.23 \text{ mg/m}^3}{154} = .0015 \text{ mg/m}^3 \text{ H}_2\text{SO}_4$$

With Vent Dilution

$$\frac{.0015 \text{ mg/m}^3}{1.5} = .001 \text{ mg/m}^3 \text{ H}_2\text{SO}_4$$

Etch Station No. 4

Emissions same as Etch Station No. 16

Etch Station No. 5

No Emission

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Etch Station No. 6

63% H_3PO_4 , Estimated Partial Vapor Pressure @ $20^\circ\text{C} \approx .0005$ tor

16% CH_3COOH , Estimated Partial Vapor Pressure @ $20^\circ\text{C} \approx .50$ tor

2% HNO_3 , Estimated Partial Vapor Pressure @ $20^\circ\text{C} \approx .0008$ tor

H_3PO_4 Equilibrium Concentration

$$\frac{.0005 \text{ tor}}{760 \text{ tor}} \times 98.00 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 2.87 \text{ mg/m}^3$$

Maximum Concentration from Station No. 6

$$\frac{2.87 \text{ mg/m}^3}{154} = .018 \text{ mg/m}^3 \text{ H}_3\text{PO}_4$$

With Vent Dilution

$$\frac{.018 \text{ mg/m}^3}{1.5} = .012 \text{ mg/m}^3 \text{ H}_3\text{PO}_4$$

CH_3COOH Equilibrium Concentration

$$\frac{.5 \text{ tor}}{760 \text{ tor}} \times 60.05 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 1763 \text{ mg/m}^3$$

Maximum Concentration from Station No. 6

$$\frac{1763 \text{ mg/m}^3}{154} = 11.45 \text{ mg/m}^3 \text{ CH}_3\text{COOH}$$

With Vent Dilution

$$\frac{11.45 \text{ mg/m}^3}{1.5} = 7.6 \text{ mg/m}^3 \text{ CH}_3\text{COOH}$$

HNO_3 Equilibrium Concentration

$$\frac{.0008 \text{ tor}}{760 \text{ tor}} \times 63.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 2.96 \text{ mg/m}^3$$

Maximum Concentration from Station No. 6

$$\frac{2.96 \text{ mg/m}^3}{154} = .019 \text{ mg/m}^3 \text{ HNO}_3$$

With Vent Dilution

$$\frac{.019 \text{ mg/m}^3}{1.5} = .013 \text{ mg/m}^3 \text{ HNO}_3$$

Etch Station No. 7

65% H_2SO_4 , Estimated Partial Vapor Pressure @ $50^\circ\text{C} \approx .0025$ tor23% HNO_3 , Estimated Partial Vapor Pressure @ $50^\circ\text{C} \approx .100$ tor H_2SO_4 Equilibrium Concentration

$$\frac{.0025 \text{ tor}}{760 \text{ tor}} \times 98.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 14.4 \text{ mg/m}^3$$

Maximum Concentration from Station No. 7

$$\frac{14.4 \text{ mg/m}^3}{154} = .094 \text{ mg/m}^3 \text{ H}_2\text{SO}_4$$

With Vent Dilution

$$\frac{.094 \text{ mg/m}^3}{1.5} = .062 \text{ mg/m}^3 \text{ H}_2\text{SO}_4$$

 HNO_3 Equilibrium Concentration

$$\frac{.100 \text{ tor}}{760 \text{ tor}} \times 63.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 369.9 \text{ mg/m}^3$$

Maximum Concentration from Station No. 7

$$\frac{369.9 \text{ mg/m}^3}{154} = 2.40 \text{ mg/m}^3 \text{ HNO}_3$$

With Vent Dilution

$$\frac{2.4 \text{ mg/m}^3}{1.5} = 1.60 \text{ mg/m}^3 \text{ HNO}_3$$

Etch Station No. 8

No Emissions

Etch Station No. 9

100% Acetone, Estimated Partial Vapor Pressure @ $20^\circ\text{C} \approx 200$ tor

$$\frac{200 \text{ tor}}{760 \text{ tor}} \times 58.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 682,287 \text{ mg/m}^3$$

Maximum Concentration from Station No. 9

$$\frac{682,287 \text{ mg/m}^3}{154} = 4430 \text{ mg/m}^3 \text{ Acetone}$$

With Vent Dilution

$$\frac{4430 \text{ mg/m}^3}{1.5} = 2953 \text{ mg/m}^3 \text{ Acetone}$$

Etch Station No. 10

100% Trichlorethylene, Estimated Partial Vapor Pressure @ 20°C ≈ 70 tor

Equilibrium Concentration of Trichlorethylene

$$\frac{70 \text{ tor}}{760 \text{ tor}} \times 131.4 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 540,261 \text{ mg/m}^3$$

Maximum Concentration from Station No. 10

$$\frac{540,261 \text{ mg/m}^3}{154} = 3508 \text{ mg/m}^3 \text{ Trichlorethylene}$$

With Vent Dilution

$$\frac{3508 \text{ mg/m}^3}{1.5} = 2338 \text{ mg/m}^3 \text{ Trichlorethylene}$$

Etch Station No. 11

29% Propanol, Estimated Partial Vapor Pressure @ 20°C ≈ 8 tor

Equilibrium Concentration of Propanol

$$\frac{8 \text{ tor}}{760 \text{ tor}} \times 60.11 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 28,182 \text{ mg/m}^3$$

Maximum Concentration from Station No. 11

$$\frac{28,182 \text{ mg/m}^3}{154} = 183 \text{ mg/m}^3 \text{ Propanol}$$

With Vent Dilution

$$\frac{183 \text{ mg/m}^3}{1.5} = 122 \text{ mg/m}^3 \text{ Propanol}$$

Etch Station No. 12

No Emissions

Etch Station No. 13

85% H_3PO_4 , Estimated Partial Vapor Pressure @ $20^\circ\text{C} \approx 0.0010$ tor

Equilibrium Concentration of H_3PO_4

$$\frac{0.001 \text{ tor}}{760 \text{ tor}} \times 98.00 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 5.74 \text{ mg/m}^3$$

Maximum Concentration from Station No. 13

$$\frac{5.74 \text{ mg/m}^3}{154} = .037 \text{ mg/m}^3 \text{ H}_3\text{PO}_4$$

With Vent Dilution

$$\frac{.037 \text{ mg/m}^3}{1.5} = .025 \text{ mg/m}^3 \text{ H}_3\text{PO}_4$$

Etch Station No. 14

Same As From Station No. 1

Etch Station No. 15

No Emission

Etch Station No. 16

98% H_2SO_4 , Estimated Partial Vapor Pressure @ $20^\circ\text{C} \approx .0033$ tor

Equilibrium Concentration of H_2SO_4

$$\frac{.0033 \text{ tor}}{760 \text{ tor}} \times 98.08 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 18.97 \text{ mg/m}^3$$

Maximum Concentration from Station No. 16 or No. 4

$$\frac{18.97 \text{ mg/m}^3}{154} = .123 \text{ mg/m}^3 \text{ H}_2\text{SO}_4$$

With Vent Dilution

$$\frac{.123 \text{ mg/m}^3}{1.5} = .082 \text{ mg/m}^3 \text{ H}_2\text{SO}_4$$

Etch Station No. 17

No Emission

Etch Station No. 18

9.8% HF, Estimated Partial Vapor Pressure @ 50°C \approx 0.065 tor

Equilibrium Concentration of HF

$$\frac{.065 \text{ tor}}{760 \text{ tor}} \times 20.01 \text{ g/mol} \times 44.64 \text{ mol/m}^3 \times 1000 \text{ mg/g} = 76.2 \text{ mg/m}^3$$

Maximum Concentration from Station No. 18

$$\frac{76.2 \text{ mg/m}^3}{154} = .49 \text{ mg/m}^3 \text{ HF}$$

With Vent Dilution

$$\frac{.49 \text{ mg/m}^3}{1.5} = .33 \text{ mg/m}^3 \text{ HF}$$

DAILY TOTAL MASS EMISSIONS PRODUCED BY DILUTION OF ETCH STATION EXHAUST
(FROM FIGURE 13) WITH TOTAL FACILITY EXHAUST

$127 \text{ m}^3/\text{min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 182880 \text{ Mass Flow Conversion Factor}$

HF Total Output

$$.79 \text{ mg/m}^3 \times 182880 = 145 \text{ g/day}$$

HCl Total Output

$$.004 \text{ mg/m}^3 \times 182880 = .732 \text{ g/day}$$

HNO_3 Total Output

$$1.74 \text{ mg/m}^3 \times 182880 = 318 \text{ g/day}$$

H_2SO_4 Total Output

$$.785 \text{ mg/m}^3 \times 182880 = 144 \text{ g/day}$$

H_3PO_4 Total Output

$$.037 \text{ mg/m}^3 \times 182880 = 6.77 \text{ g/day}$$

Acetic Acid Total Output

$$7.6 \text{ mg/m}^3 \times 182880 = 1390 \text{ g/day}$$

Acetone Total Output

$$2953 \text{ mg/m}^3 \times 182880 = 540 \text{ Kg/day}$$

Trichlorethylene Total Output

$$2338 \text{ mg/m}^3 \times 182880 = 428 \text{ Kg/day}$$

Propanol Total Output

$$122 \text{ mg/m}^3 \times 182880 = 22 \text{ Kg/day}$$

6

PHOTORESIST

6. PHOTORESIST

The following assumptions were made in calculating emissions from the photoresist area:

- (a) A throughput of 25 wafers per day was assumed.
- (b) The Hunt Waycoat photoresist was assumed with the usage of 5 drops per wafer. The vent flow of 1,280 cubic feet per minute was assumed.

As indicated in the summary chart, the emissions from the Waycoat material principally Xylene is well within the OSHA limits.

PHOTORESIST OPERATION

XYLENE EMISSIONS (From Waycoat #3 Photoresist)	<u>PHOTORESIST</u>	<u>OSHA LIMITS</u>
ppm	0.3	100
mg/m ³	1.88	433
g/day	97.9	

PHOTORESIST OPERATION EMISSIONS

	<u>XYLENE</u>	<u>STODDARD SOLVENT</u>	<u>N-BUTYL ACETATE</u>
PHOTORESIST APPLICATION (Spin & Bake)			
ppm, Average	.056		
mg/m ³ , Average	.361		
g/day, Average	97.9		
PHOTORESIST DEVELOPMENT (Develop & Bake)			
ppm, Average		.044	.020
ppm, Peak		31	14.8
mg/m ³ , Average		.186	.134
mg/m ³ , Peak		130	92.2
g/day		50.6	36.3
OSHA LIMIT			
ppm	100	200	150
mg/m ³	435	1150	710

PHOTORESIST APPLICATION, SPIN AND BAKE

25 wafer/day Using 5 drops/wafer

5 drops x 1 cc/drop x 25 wafer/day = 125 cc/day

Hunt Waycoat #3 @ 45 Centipoise

87 wt% Xylene

13 wt% Solids

.90 SP GR (Water = 1.0)

125 cc/day x .90 SPGR x .87 = 97.9 g/day Xylene Total Emission

Vent Flow 1280 cfm

1280 cfm x .0283 m³/cf x 60 min/hr x 24 hr/day = 52,162 m³/day

$\frac{97.9 \text{ g/day} \times 1000 \text{ mg/g}}{52,162 \text{ m}^3/\text{day}} = 1.88 \text{ mg/m}^3$ Xylene in Hood Exhaust

OSHA Limit is 435 mg/m³

Xylene Emissions

$\frac{97.9 \text{ g/day}}{106.17 \text{ g/mol}} \times 22.4 \text{ l/mol} = 20.7 \text{ l/day}$ Xylene

$\frac{20.7 \text{ l/day}}{52,162,000 \text{ l/day (vent flow)}} = .3 \text{ ppm Xylene}$

With Total Exhaust Dilution

$\frac{1.88 \text{ mg/m}^3 \times 36.1 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .361 \text{ mg/m}^3$ Xylene

$\frac{.3 \text{ ppm} \times 36.1 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .056 \text{ ppm Xylene}$

Daily Total Mass Emission

.361 mg/m³ x 188.7 m³/min x 60 min/hr x 24 hr/day = 97.9 g/day

PHOTORESIST DEVELOP AND BAKE

Assume 25 cc of Stoddard Solvent sprayed in 5 sec and 25 cc of N-Butyl acetate sprayed in 5 sec for each wafer developed. Assume 25 wafers/day processed.

Estimated Vapor Press @ 20° C	<u>Plane Surface</u>	<u>Spray Drop</u>
Stoddard Solvent	45 ton	90 ton
N-Butyl Acetate	25 ton	50 ton
Total Liquid Spray Volume		
Stoddard Solvent	625cc/Day	
N-Butyl Acetate	625cc/Day	

Photoresist Develop,

Stoddard Solvent, Total Exhaust Dilution, Average Emission

$$\frac{90/\text{ton}}{760/\text{ton}} \times 625 \text{ cc} = 74 \text{ cc/day Liquid Vaporized}$$

Liquid volume to vapor volume factor is 162.6
 $74 \text{ cc/day} \times 162.6 = 12,026 \text{ cc/day Vapor Volume}$

$$\frac{12,026 \text{ cc/day}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/m}^3 \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .044 \text{ pm Daily Average}$$

200 ppm OSHA Limit

$$74 \text{ cc/day} \times .684 \text{ g/cc} = 50.6 \text{ g/day Total Stoddard Solvent}$$

$$\frac{50,600 \text{ mg/day}}{188.7 \text{ m}^3/\text{min} \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .186 \text{ mg/m}^3 \text{ Daily Average}$$

OSHA Limit 1150 mg/m^3

STODDARD SOLVENT, TOTAL EXHAUST, PEAK EMISSION

$$\frac{90 \text{ tor}}{760 \text{ tor}} \times 25 \text{ cc} = 3.0 \text{ cc/5 sec} \quad \text{Liquid Vaporized}$$

Liquid Volume to Vapor Volume Factor is 162.6

$$3.0 \text{ cc/5 sec} \times 162.6 = 488 \text{ ml/5 sec} \quad \text{Vapor Volume}$$

$$\frac{488 \times 12 \text{ spray periods/min}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/m}^3} = 31 \text{ ppm} \quad \text{Peak Emission}$$

OSHA Limit 200 ppm

$$3.0 \text{ ml/5 sec} \times .684 \text{ g/cc} = 2.05 \text{ g/5 sec}$$

$$\frac{2050 \text{ mg/5 sec} \times 12 \text{ spray periods/min}}{188.7 \text{ m}^3/\text{min}} = 130 \text{ mg/m}^3 \quad \text{Peak Emission}$$

OSHA Limit 1150 mg/m³

Photoresist Develop

N-Butyl Acetate, Total Exhaust Dilution, Average Emission

$$\frac{50 \text{ tor}}{760 \text{ tor}} \times 625 \text{ cc} = 41.1 \text{ cc/day} \quad \text{Liquid Vaporized}$$

Liquid Volume to Vapor Volume Factor is 142.1

$$41.1 \text{ cc} \times 142.1 = 5841 \text{ cc/day} \quad \text{Vapor Volume}$$

$$\frac{5841 \text{ cc/day}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc/m}^3 \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .02 \text{ ppm Daily Average}$$

OSHA Limit 150 ppm

$$41.1 \text{ cc/day} \times .883 \text{ g/cc} = 36.3 \text{ g/day}$$

$$\frac{36,300 \text{ mg/day}}{188.7 \text{ m}^3/\text{min} \times 60 \text{ min/hr} \times 24 \text{ hr/day}} = .134 \text{ mg/m}^3 \quad \text{Daily Average}$$

OSHA Limit 710 mg/m³

N-BUTYL ACETATE, TOTAL EXHAUST, PEAK EMISSION

$$\frac{50 \text{ tor}}{760 \text{ tor}} \times 25 \text{ cc} = 1.64/5 \text{ sec Liquid Vaporized}$$

Liquid Volume to Vapor Volume Factor is 142.1

$$1.64 \text{ cc} \times 142.1 = 233 \text{ cc}/5 \text{ sec Vapor Volume}$$

$$\frac{233 \times 12 \text{ sprays}/5 \text{ sec}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc}/\text{m}^3} = 14.8 \text{ ppm Peak Emission}$$

OSHA Limit 150 ppm

$$1.64 \text{ cc}/5 \text{ sec} \times .883 = 1.45 \text{ g}/5 \text{ sec}$$

$$\frac{1450 \text{ mg}/5 \text{ sec} \times 12 \text{ sprays}/5 \text{ sec}}{188.7 \text{ m}^3/\text{min}} = 92.2 \text{ mg}/\text{m}^3 \text{ Peak Emission}$$

OSHA Limit 710 mg/m³

Photoresist Bake

Stoddard Solvent, N-Butyl Acetate, Total Exhaust Dilution, Average Emission

Assume photoresist film thickness of 1 and 25% absorption of solvent.

$$\frac{(3 \times 2.54)^2 \text{ cm}}{2} \times \pi \times 1 \times 10^{-4} \text{ cm} = .0015 \text{ cc/wafer Photoresist Volume}$$

$$.0015 \text{ cc} \times 25\% = .0004 \text{ cc Solvent/Wafer}$$

$$.004 \text{ cc} \times 25 \text{ wafer/day} = .0015 \text{ cc/day Solvent Liquid Volume}$$

Liquid Volume to Vapor Volume Factor is 149.6

$$.0015 \text{ cc/day} \times 149.6 = .224 \text{ cc/day Vapor Volume from Bake Out}$$

$$\frac{.224 \text{ cc/day}}{188.7 \text{ m}^3/\text{min} \times 1,000,000 \text{ cc}/\text{min} \times 60 \text{ min}/\text{hr} \times 24 \text{ hr}/\text{day}} = .0000008 \text{ ppm Daily Average}$$

Contribution from bake is negligible

7

EXPITAXIAL
OPERATION

7. EPITAXIAL OPERATION

As indicated on the master plan this particular operation has a separate exhaust system and will utilize a gas scrubbing operation.

There are four major concerns with the epi system.

- (a) Use of hydrogen and its concentration. Provisions must be made for hydrogen burn-off or maintaining the hydrogen concentration within a noncombustible ratio.
- (b) The disposal of the amount of the various dopant gases is a critical safety problem
- (c) With the scrubber in use the acidic content of the water and its drainage becomes a consideration.
- (d) Although not a safety problem, the RF generator does require a registration and a license. A typical form is attached.

Assumptions

For the problems of hydrogen gas and flammability conditions a normal flow of five liters per minute was assumed, and a maximum potential flow of 110 liters per minute was assumed from one chamber. Reviewing the calculations in Figure A it can be seen that a percent of hydrogen and air must be kept less than 4 percent or greater than 75 percent to be safe. Because of potential variable amounts hydrogen used, ranging from five liters per minute to maximum possible of a 110 liters per minute, more than 330 liters per minute of air would have to be added to assure that the hydrogen would stay in a safe area. (See Figure B) Thus, ICE would recommend a burn-off procedure to handle the hydrogen prior to the scrubber.

Other assumptions made for the epitaxial reactor assumed a normal case of 1 chamber operating and a worse case of 2 chambers operating. Figure C shows the potential amount of various materials which will be omitted from the eptaxial reactor for normal or worse case conditions. It should be noted that in almost every case this value exceeds OSHA limits, thus, a scrubber is absolutely necessary.

FORM 724
December 1945

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

FORM APPROVED
BUDGET BUREAU NO. 52-R174.2

CERTIFICATE OF COMPLIANCE - INDUSTRIAL, SCIENTIFIC AND MEDICAL EQUIPMENT

READ INSTRUCTIONS ON
PAGE 4 CAREFULLY BE-
FORE FILLING OUT THIS
FORM.

**PART I
CERTIFICATION REGARDING OPERATION**

Name of firm
is responsible for the operation of the ISM equipment listed on page 2 of this form at the following location:

FLOOR OF BLDG. OR OTHER LOCATION
STREET AND NUMBER
CITY, COUNTY AND STATE

I HEREBY CERTIFY THAT:

I am familiar with Part 18 of the FCC Rules pertaining to the operation of the equipment listed on page 2 of this Form; and
I have assured myself that this installation does not cause harmful interference. If harmful interference arises, I will take
prompt steps to eliminate the harmful interference; and

If a prototype certification for this equipment has been filed with the FCC, I have had the equipment installed in exact ac-
cordance with the instructions furnished by the manufacturer; and

If a prototype certification for this equipment has NOT been filed with the FCC, I have attached the report of measurements
of the RF energy emitted by the equipment; I have read this report and confirm that the data contained therein are true, correct,
and complete of my own knowledge, except for such data as were obtained from measurements or observations made by other
persons as to which I am informed and believe the same to be true; and if the measurements were made at a location other than
the site of operation listed above, I have had the equipment installed in exact accordance with the instructions furnished by
the manufacturer.

Dated this day of, 19.....

BY(SIGNATURE):	NAME OF FIRM:		
NAME (PRINT):	BUSINESS ADDRESS:	STREET	NUMBER
TITLE:	CITY	STATE	ZIP CODE

**PART II
CERTIFICATION BY CORPORATION CONCERNING SIGNATURE OF EMPLOYEE**

I HEREBY CERTIFY THAT:

The person who signed Part I of this Certificate and who is named below is in the employ of the corporation named below
and has supervisory responsibility for the operation of the equipment named in this Certificate; and that the corporation named
below accepts full responsibility for his action.

Dated this day of, 19.....

BY(SIGNATURE):	NAME OF AUTHORIZED EMPLOYEE:
NAME (PRINT):	NAME OF CORPORATION:
TITLE:	MAIL ADDRESS OF CORPORATION:

WARNING

FALSE STATEMENTS ON THIS FORM ARE PUNISHABLE BY IMPRISONMENT FOR NOT MORE THAN FIVE
YEARS AND A FINE OF NOT MORE THAN \$10,000. TITLE 18, U. S. CODE, SECTION 1001.

FIGURE A

EPI OPERATIONS

EPI Operations, Hydrogen Gas Disposal

Assume normal flow of 5 l/min and maximum flow of 110 l/min in one chamber. Determine minimum air dilution to stay below 4% flamability limit and maximum air dilution to stay above the 75% flamability limit. (Assume burnoff not in use)

At 5 l/min

$\frac{5 \text{ l/min}}{.75} - 5 \text{ l/min} = 1.67 \text{ l/min}$ - Maximum Air Addition to Exhaust Gas to Stay Above Upper Explosive Limit

$\frac{5 \text{ l/min}}{.04} - 5 \text{ l/min} = 120 \text{ l/min}$ - Minimum Air Addition to Exhaust Gas to Stay Below Lower Explosive Limit

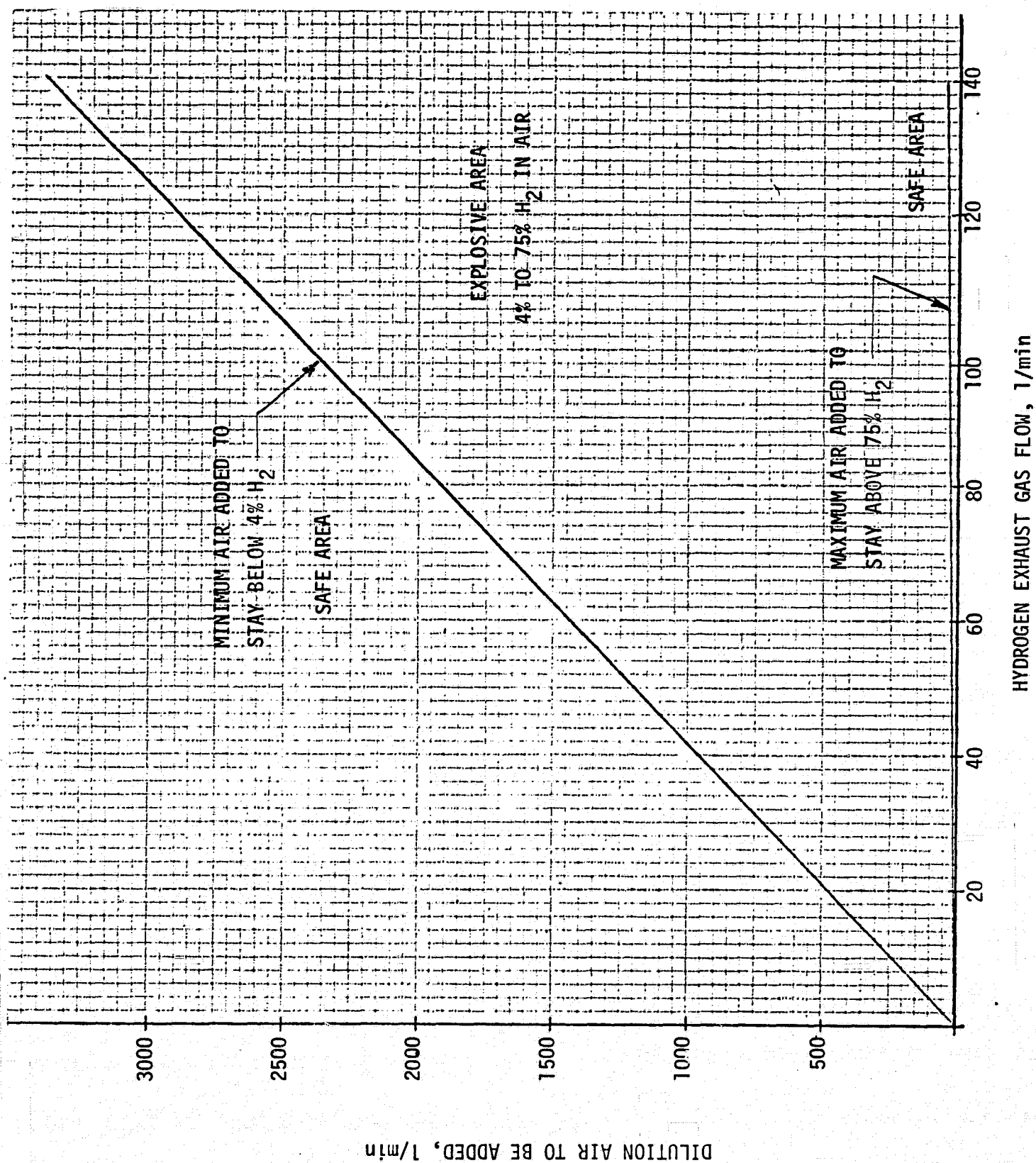
At 110 l/min

$\frac{110 \text{ l/min}}{.75} - 110 \text{ l/min} = 36.7 \text{ l/min}$ - Maximum Air Addition to Exhaust Gas to Stay Above Upper Explosive Limit

$\frac{110 \text{ l/min}}{.04} - 110 \text{ l/min} = 2640 \text{ l/min}$ - Minimum Air Addition to Exhaust Gas to Stay Below Lower Explosive Limit

Conclusion

Burning is safer than dilution exhausting

AIR ADDITION REQUIRED FOR NON-EXPLOSIVE,
DILUTION DISPOSAL, OF HYDROGEN GAS EXHAUSTORIGINAL PAGE IS
OF POOR QUALITY

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EPITAXY OPERATION EMISSIONS

AMMONIA (NH ₃)	SILICON GROWTH WITH SiCl ₄ SOURCE	SILICON GROWTH WITH SiH ₄ SOURCE	AMMONIA/ NITROUS OXIDE	HCl CLEANING	HCl ETCHING	OSHA LIMITS	PROBLEM AREAS	H ₂ O SOLUBILITY CC/CCl ₂ O
ppm 3			500,000			50		89/100
mg/m ³			330			35		
g/day Normal Case			228					
g/day Worst Case			456					
HYDROGEN CHLORIDE (HCl)								
ppm 3	387,000							
mg/m ³	631,000							
g/day Normal Case	7,420			750,000	200,000	5	*	82.3/100
g/day Worst Case	14,800			1,221,000	324,000			
				733	8.12			
				1,470				
NITROUS OXIDE (N ₂ O)								
ppm 3			25,300			25 (T)	*	130/100
mg/m ³			49,700					
g/day Normal Case			15.3					
g/day Worst Case			30.6					
DIBORANE (B ₂ H ₆)								
ppm 3	1.29	1.29				.1	*	DEC TO
mg/m ³	1.55	1.55				.1	*	H3803
g/day Normal Case	.0048	.0048						
g/day Worst Case	.0096	.0096						
PHOSPHINE (PH ₃)								
ppm 3	1.29	1.29				.3	*	.26/100
mg/m ³	1.90	1.90				.4	*	
g/day Normal Case	.0006	.0006						
g/day Worst Case	.0012	.0012						
ARSINE (AsH ₃)								
ppm 3	1.29	1.29				.05	*	20/100
mg/m ³	4.37	4.37				.2	*	
g/day Normal Case	.0014	.0014						
g/day Worst Case	.0028	.0028						

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OF POOR QUALITY

EPI OPERATING CONDITIONS

Hydrogen:

Flow: 110 l/min (Maximum)

Concentration: 100%

Ammonia NH_3 :

Flow: 5 l/min, 1 Hour Maximum

Concentration: 100

Hydrogen Chloride HCl :

Flow: Etch 1.25 l/min 2 min 2 Batch/Day
Clean 15 l/min 15 min 2 Cleans/Day

Concentration: 99.9%

Silicon Tetrachloride SiCl_4

Flow: 6 g/min 100% HCl Vapor Product

Concentration: 100%

Silane SiH_4

Flow: 160 cc/min

Concentration: 100%

Arsene AsH_3

Flow: 130 cc/min

Concentration: 50 ppm in H_2

Diborane B_2H_6

Flow: 130 cc/min

Concentration: 50 ppm in H_2

Phosphine PH_3

Flow: 130 cc/min

Concentration: 50 ppm in H_2

Nitrous Acid N_2O

Flow: 130 cc/min

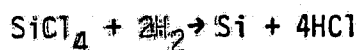
Concentration: 50 ppm in H_2

CALCULATIONS

EPI OPERATIONS

EPI Operations, Silicon Tetrachloride

Assume normal epi growth using onechamber with 6 g/min of 100% SiCl_4 diluted with 5 l/min of hydrogen.



$$\frac{6 \text{ g/min} \times 36.46 \text{ g/mol} \times 4 \text{ mol}}{169.9 \text{ g/mol}} = 5.15 \text{ g/min HCl}$$

$$\frac{5.15 \text{ g/min}}{36.46 \text{ g/mol}} \times 22.4 \text{ l/mol} = 3.16 \text{ l/min HCl}$$

$$\frac{3.16 \text{ l/min}}{5 \text{ l/min} + 3.16 \text{ l/min}} = 387.255 \text{ ppm HCl}$$

OSHA Limit is 5 ppm

One Tube

$$\frac{5150 \text{ mg/min}}{.00816 \text{ m}^3/\text{min}} = 631,127 \text{ mg/m}^3$$

Total Daily Maximum Emissions (24 hr/day)

$$5.15 \text{ g/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} = 7.416 \text{ kg/day One Tube}$$

$$\text{Two Tubes} = 14.83 \text{ kg/day}$$

EPI OPERATIONS

EPI Operations, Diborane Doping

Assume normal conditions of silicon growth using silane with one chamber using 130 cc/min of 10 ppm B_2H_6 in hydrogen diluted with normal flow of H_2 at rate of 1/min² for maximum of one hour.

$$130 \text{ cc.min} \times .000050 = .0065 \text{ cc/min } B_2H_6 \text{ input Dopant Gas}$$

$$\frac{.0065 \text{ cc/min}}{5000 \text{ cc/min} + .160 \text{ cc/min} + .0065 \text{ cc/min}} = 1.29 \text{ ppm } B_2H_6 \text{ in Exit Gas From One Chamber}$$

OSHA Limit is 0.1 ppm

$$\frac{.0000065 \text{ 1/min}}{22.4 \text{ 1/mol}} \times 27.67 \text{ g/mol} = .00802 \text{ mg.min } B_2H_6$$

One Tube

$$\frac{.00802 \text{ mg/min}}{.00517 \text{ m}^3/\text{min}} = 1.55 \text{ mg/m}^3 B_2H_6$$

Total Daily Maximum Emission (1 hour maximum run)

$$.00802 \text{ mg/min} \times 120 \text{ min} = .48/\text{mg}$$

$$\text{Two Tubes} = .96 \text{ mg}$$

EPI OPERATIONS

EPI Operations, Arsine Doping

Assume normal conditions of silicon growth using silane with one chamber using 130 cc/min of 50 ppm AsH_3 in hydrogen diluted with normal flow of H_2 at a flow of 5 l/min for maximum of 1 hour.

$$130 \text{ cc/min} \times .000050 = .0065 \text{ cc/min AsH}_3 \text{ input Dopant Gas}$$

$$\frac{.0065 \text{ cc/min}}{5000 \text{ cc/min} + .160 \text{ cc/min} + .0065 \text{ cc/min}} = 1.29 \text{ ppm AsH}_3 \text{ in Exit Gas in One Chamber}$$

OSHA Limit is 0.05 ppm

$$\frac{.0000065 \text{ l/min}}{22.4 \text{ l/mol}} \times 77.91 \text{ g/mol} = .023 \text{ mg/min AsH}_3$$

One Tube

$$\frac{.023 \text{ mg/min}}{.00517 \text{ m}^3/\text{min}} = 4.37 \text{ mg/m}^3 \text{ AsH}_3$$

Total Daily Maximum Emission (1 hour maximum run)

$$.023 \text{ mg/min} \times 60 \text{ min/hr} = 1.38 \text{ mg}$$

$$\text{Two Tubes} = 2.76 \text{ mg}$$

EPI OPERATIONS

EPI Operations, Phosphine Doping

Assume normal conditions of silicon growth using silane with one chamber using 130 cc/min of 50 ppm PH_3 in hydrogen diluted with normal flow of H_2 at rate of 5 l/min for maximum of 1 hour.

$$130 \text{ cc.min} \times .000050 = .0065 \text{ cc/min } \text{PH}_3 \text{ input Dopant Gas}$$

$$\frac{.0065 \text{ cc/min}}{5000 \text{ cc/min} + .160 \text{ cc/min} + .0065 \text{ cc/min}} = 1.29 \text{ ppm } \text{PH}_3 \text{ in Exit Gas From One Chamber}$$

OSHA Limit is 0.3 ppm

$$\frac{.0000065 \text{ l/min}}{22.4 \text{ l/mol}} \times 34 = .0099 \text{ mg/min } \text{PH}_3$$

One Tube

$$\frac{.0099 \text{ mg/min}}{.00517 \text{ m}^3/\text{min}} = 1.9 \text{ mg/m}^3 \text{ } \text{PH}_3$$

Total Daily Maximum Emission (1 Hour Maximum Run)

$$.0099 \text{ mg/min} \times 60 \text{ min} = .594 \text{ mg}$$

$$\text{Two Tubes} = 1.19 \text{ mg}$$

EPI OPERATION

EPI Operation, Ammonia Gas

Assume normal operations of 1 chamber and maximum of 2 chambers with 5 l/min of 100% NH_3 gas diluted with 5 l/min hydrogen for a time period of 1 hour maximum.

$$\frac{5 \text{ l/min}}{5 \text{ l/m} + 5 \text{ l/m}} = 500,000 \text{ ppm of } \text{NH}_3 \text{ in Exit Gas}$$

OSHA Limit is 50 ppm

$$\frac{5 \text{ l/min}}{22.4 \text{ l/mol}} \times 17.03 \text{ g/mol} = 3.80 \text{ g/min } \text{NH}_3$$

One Tube

$$\frac{3800 \text{ mg/min}}{.010 \text{ m}^3/\text{min}} = 380 \text{ mg/m}^3 \text{ } \text{NH}_3$$

Total Daily Maximum Emission (1 Hour Maximum Run)

$$3.80 \text{ g/min} \times 60 \text{ min} = 228 \text{ g}$$

$$\text{Two Tubes} = 456 \text{ g}$$

EPI OPERATION

EPI Operation, Nitrous Oxide Gas

Assume normal operation of 1 chamber suing 130 cc/min of 100% N₂O diluted with 5 l.min of H₂ for maximum of 1 hour.

$$\frac{130 \text{ cc/min}}{5000 \text{ l/min} + 130 \text{ cc/min}} = 25,341 \text{ ppm N}_2\text{O in Exit Gas From One Chamber}$$

OSHA Limit is 25 ppm (Tentative)

$$\frac{.130 \text{ l/min}}{22.4 \text{ l/mol}} \times 44.01 \text{ g/mol} = .255 \text{ g/min N}_2\text{O}$$

One Tube

$$\frac{225 \text{ mg/min}}{.00517 \text{ m}^3/\text{min}} = 49,707 \text{ mg/m}^3 \text{ NH}_3$$

Total Daily Emission (1 Hour Maximum Run)

$$\begin{aligned} .255 \text{ g/min} \times 60 \text{ min} &= 15.3 \text{ g} \\ \text{Two Tubes} &= 30.6 \text{ g} \end{aligned}$$

EPI OPERATION

EPI Operation, Hydrogen Chloride Gas

Assume normal etching operations of 1 chamber, with 2 batches/day of 1.25 l/min of 99.99 HCl for a time period of 2 min. diluted with a hydrogen flow of 5 l/min.

$$\frac{1.25 \text{ l/min}}{5 \text{ l/min} + 1.25 \text{ l/min}} = 200,000 \text{ ppm HCl in Exit Gas During Each Batch}$$

Assume normal cleaning operations of 1 chamber with 2 cleans/day of 15 l/min of 99.99 HCl for a time period of 15 min. diluted with 5 l/min flow of hydrogen.

Normal Cleaning

$$\frac{15 \text{ l/min}}{5 \text{ l/min} + 15 \text{ l/min}} = 750,000 \text{ ppm HCl in Exit Gas During Each Batch}$$

OSHA Limit is 5 ppm

EPI OPERATION

EPI Operation, Hydrogen Chlorine Gas

Etching

$$\frac{1.25 \text{ l/min}}{22.4 \text{ l/mol}} \times 36.46 \text{ g/mol} = 2.03 \text{ g/min HCl}$$

One Tube

$$\frac{2030 \text{ mg/min}}{0.00625 \text{ m}^3/\text{min}} = 324,800 \text{ mg/m}^3 \text{ HCl}$$

Total Daily Emission

2 Batches/day for 2 min duration (1 tube)

$$2.03 \text{ g/min} \times 4 \text{ min} = 8.12 \text{ g HCl}$$

Two Tubes (2 Batch for 2 Min.)

$$8.12 \text{ g} \times 2 = 16.24 \text{ g HCl}$$

EPI OPERATION

EPI Operation, Hydrogen Chloride Gas

Cleaning

$$\frac{15 \text{ l/min}}{22.4 \text{ l/mol}} \times 36.46 \text{ g/mol} = 24.42 \text{ g/min HCl}$$

One Tube

$$\frac{24,442 \text{ mg/min}}{.02 \text{ m}^3/\text{min}} = 1,221,000 \text{ mg/m}^3 \text{ HCl}$$

Total Daily Emission

2 Cleans/day for 15 min. duration (1 Tube)

$$24.42 \text{ g/min} \times 30 \text{ min} = 732.6 \text{ g HCl}$$

Two Tubes

$$732.6 \text{ g} \times 2 = 1.465 \text{ kg HCl}$$

8

SCRUBBER

8. SCRUBBERS

Based upon the system requirements for a scrubber at the exhaust gas outlet, ICE performed the calculations to determine the requirements for the scrubber, considering the total air flow and the various chemicals involved. As shown in Figure D, a total of 188 cubic meters per minute of air flow will go in the scrubbers. Typical industry requirements has suggested the use of three DFC0623 scrubber modules or equivalent to provide a sufficient handling capability for this exhaust gas flow. In addition a total of 15 gallons per minute of water will be required.

Because of various gases and chemicals entering the scrubbers, the pH of the liquid effluent is a factor. A particular requirement will be to neutralize the various acids, including hydrochloric acid which is above the OSHA limit. A limestone bed will be required. As indicated by the calculations, for normal case daily usage a total of 15 pounds of limestone per day would be utilized and under worse case conditions a total of 22 pounds per day.

FIGURE D

<u>SOURCE</u>	<u>m³/min INERT GAS</u>	<u>m³/min AIR</u>	<u>m³/min H₂</u>	<u>m³/min TOTAL</u>	<u>cfm TOTAL</u>
Etch Station	-	127	-	127	4500
Diffusion	.06	25.5	-	25.5	900
CVD	-	-	-	-	-
Photoresist	-	36.2	-	36.2	1280
TOTAL	.06	188.7	0	188.7	6680

Use 3 - DSE U623 Scrubber modules

2300 cfm x 3 = 6900 cfm Exhaust

5 cfm x 3 = 15 gmp Water

15 gpm x 3785 cc/gal = 56,775 cc/min

CHEMICAL REMOVAL IN SCRUBBER

COMBINED EXHAUST FROM DIFFUSION, CVD, PHOTORESIST AND ETCH STATIONS.

AMMONIA

NH_3 solubility = 89.9 g/100 cc = .899 g/cc at ambient temperature

.899 g/cc x 56,775 cc/min = 51,040 g/min NH_3 maximum solubility rate achievable

NH_3 Production, assume total daily effluent is charged to scrubber in 30 min. run.

Normal Case = 87.8 g/day = 87.8 g/30 min. = 2.93 g/min.

51,040 g/min > 2.93 g/min. = complete removal

Worst Case = 176 g/day = 176 g/30 min. = 5.87 g/min.

51,000 g/min > 5.87 g/min = Complete removal

Thus no significant level of NH_3 in scrubber exit gas. All NH_3 in scrubber liquid.

In either case scrubber liquid effluent pH will go up slightly because of resulting NH_4OH production.

HYDROGEN CHLORIDE

HCl Solubility = 80 g/100cc = .80 g/cc at ambient temperature

.80 g/cc x 56,775 cc/min = 45,420 g/min maximum solubility rate achievable

HCl Production, assume total daily effluent is charge to scrubber in 30 min. run.

Normal Case = 1054 g/day = 1054 g/30 min. = 35.13 g/min.

45,420 g/min > 35.13 g/min. = complete removal

Worst Case = 2459 g/day = 2459 g/30 min. = 82 g/min.

45,520 g/min > 82 g/min. = complete removal

Thus no significant level of HCl in scrubber exit gas. All HCl in scrubber liquid.

HYDROGEN CHLORIDE NEUTRALIZATION

HCl reactivity with limestone bed is as follows:



Normal Case = 1054 g/day HCl

$$1054 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{2(36.46) \text{ g/mol}} = 1446 \text{ g/day}$$

$$\frac{1446 \text{ g/day}}{454 \text{ g/lb}} = 3.19 \text{ lb/day Limestone}$$

Assume 50% reagent efficiency (based on surface of pebble bed)

$$3.19 \text{ lb/day} \times 2 = 6.38 \text{ lb/day Limestone required for HCl neutralization}$$

Worst Case = 2459 g/day HCl

$$2459 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{2(36.46) \text{ g/mol}} = 3080 \text{ g/day}$$

$$\frac{3080 \text{ g/day}}{454 \text{ g/lb}} = 6.79 \text{ lb/day Limestone}$$

Assume 50% reagent efficiency

$$6.79 \text{ lb/day} \times 2 = 13.6 \text{ lb/day Limestone required for HCl neutralization}$$

NITROUS OXIDE

N_2O Solubility = .12 g/cc at ambient temperature

.12 g/cc x 56,775 cc/min = 6813 g/min. N_2O maximum solubility rate achievable

N_2O Production. Assume total daily effluent is charged to scrubber in 30 min. run.

Normal Case = 282 g/day = 564 g/30 min. = 9.4 g/min.

6813 g/min > 9.4 g/min. = Complete Removal

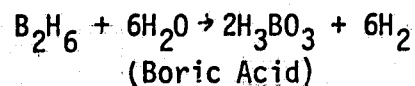
Worst Case = 564 g/day = 564 g/30 min = 18.8 g/min.

6813 g/min > 18.4 g/min = Complete Removal

Thus no significant level of N_2O in scrubber exit gas. All N_2O in scrubber liquid.

DIBORANE

B_2H_6 is slightly soluble in ambient temperature. When it dissolves in water it reacts as follows:



With this slight solubility, production of boric acid and the subsequent reaction of boric acid with limestone it can be assumed that negligible amounts of diborane will exist in the scrubber exit gas.

PHOSPHINE

PH_3 Solubility = 26 cc gas/100 cc water at ambient temperature

$$\frac{.026 \text{ l}}{22.4 \text{ l/mol}} \times 77.95 \text{ g/mol} = .090 \text{ PH}_3 \text{ Gas in 100 cc water}$$

$$.090 \text{ g/100 cc} = .0009 \text{ g/cc}$$

.0009 g/cc x 56,775 cc/min = 51.1 g/min PH_3 Maximum solubility rate achievable

PH_3 Production. Assume total daily effluent is charged to scrubber in 30 min. run.

$$\text{Normal Case} = 173 \text{ g/day} = 173 \text{ g/30 min.} = 5.77 \text{ g/min.}$$

$$51.1 \text{ g/min} > 5.77 \text{ g/min} = \text{complete removal}$$

$$\text{Worst Case} = 347 \text{ g/day} = 347 \text{ g/30 min.} = 11.6 \text{ g/min.}$$

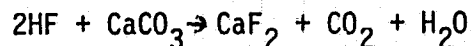
$$51.1 \text{ g/min.} > 11.6 \text{ g/min} = \text{complete removal}$$

Thus no significant level of PH_3 exists in scrubber exit gas.
All PH_3 in scrubber liquid.

HYDROFLUORIC ACID

HF is infinitely soluble in scrubber water under normal conditions, therefore no vapor HF emission is assumed in scrubber exit gas.

HF will react with limestone bed as follows:



Normal Case = 144 g/day HF

$$144 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{2(20.01) \text{ g/mol}} = 361 \text{ g/day} \div 454 = 0.8 \text{ lb/day Limestone}$$

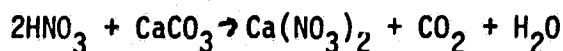
Assume 50% reagent reactivity efficiency

$$0.8 \text{ lb/day} \times 2 = 1.6 \text{ lb/day Limestone required for HF neutralization.}$$

NITRIC ACID

HNO_3 is infinitely soluble in scrubber water under normal conditions, therefore no vapor HNO_3 emission is assumed on scrubber exit gas.

HNO_3 will react with limestone bed as follows:



Normal Case = 318 g/day HNO_3

$$318 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{2(63.01 \text{ g/mol})} = 253 \text{ g/day} \div 454 = 0.6 \text{ lb/day Limestone}$$

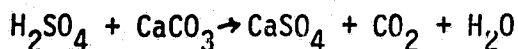
Assume 50% reagent reactivity efficiency

$$0.6 \text{ lb/day} \times 2 = 1.2 \text{ lb/day Limestone required to neutralize } \text{HNO}_3$$

SULFURIC ACID

H_2SO_4 is infinitely soluble in scrubber water under normal conditions, therefore no vapor H_2SO_4 emission is assumed in scrubber exit gas.

H_2SO_4 will react with limestone bed as follows:



Normal Case = 144 g/day H_2SO_4

$$144 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{98.08 \text{ g/mol}} = 147 \text{ g/day} \div 454 = 0.3 \text{ lb/day Limestone}$$

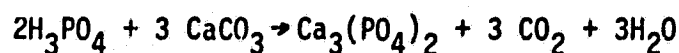
Assume 50% reagent reactivity efficiency

$$0.3 \text{ lb/day} \times 2 = 0.6 \text{ lb/day Limestone required to neutralize } \text{H}_2\text{SO}_4$$

PHOSPHORIC ACID

H_3PO_4 is very soluble in scrubber water under normal conditions, therefore H_3PO_4 emission is assumed in scrubber exit gas.

H_3PO_4 will react with limestone bed as follows:



Normal Case = 6.8 g/day H_3PO_4

$$6.8 \text{ g/day} \times \frac{3(100.09) \text{ g/mol}}{2(98) \text{ g/mol}} = 10.4 \text{ g/day} + 454 = 0.02 \text{ lb/day Limestone}$$

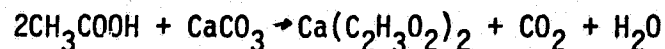
Assume 50% reagent reactivity efficiency

$$0.02 \text{ lb/day} \times 2 = 0.04 \text{ lb/day Limestone required to neutralize } H_3PO_4$$

ACETIC ACID

CH_3COOH is very soluble in scrubber water under normal conditions, therefore no vapor CH_3COOH emission is assumed in scrubber exit gas.

CH_3COOH will react with limestone bed as follows:



Normal Case = 1390 g/day CH_3COOH

$$1390 \text{ g/day} \times \frac{100.09 \text{ g/mol}}{2(60.05) \text{ g/mol}} = 1158 \text{ g/day} + 454 = 2.6 \text{ lb/day Limestone}$$

Assume 50% reagent reactivity efficiency

$$2.6 \text{ lb/day} \times 2 = 5.2 \text{ lb/day Limestone required to neutralize } CH_3COOH$$

ACETONE

CH_3COCH_3 is infinitely soluble in scrubber water under normal conditions, therefore CH_3COCH_3 emission is assumed in scrubber exit gas.

TRICHLORETHYLENE

Trichlorethylene is only very slightly soluble in scrubber water under normal conditions, therefore it is assumed that all trichlorethylene emission is present in the scrubber exit gas.

PROPANOL


Propanol is infinitely soluble in scrubber water under normal conditions, therefore no vapor emission of propanol is assumed to exist in scrubber exit gas.

STODDARD SOLVENT

This petroleum solvent is essentially insoluble in the scrubber water under normal conditions, therefore it is assumed the total emission is present in the scrubber exit gas.

XYLENE

This aromatic hydrocarbon is essentially insoluble in the scrubber water under normal conditions. Therefore, it is assumed that the total emission is present in the scrubber exit gas.




BUTYL ACETATE

This organic ester is only very slightly soluble in the scrubber water under normal conditions. Therefore, it is assumed that the total emission is present in the scrubber exit gas.

SCRUBBER LIMESTONE CONSUMPTION

REACTANT	NORMAL CASE DAILY USAGE, lb	WORST CASE DAILY USAGE, lb
HCl	6.38	13.6
HF	1.6	1.6
HNO ₃	1.2	1.2
H ₂ SO ₄	0.6	0.6
H ₃ PO ₄	0.04	0.04
CH ₃ COOH	<u>5.2</u>	<u>5.2</u>
	15.02	22.24

When any ammonia is present in the scrubber water it will react with these six acids to reduce the consumption of limestone. Any ammonium salts (e.g. NH₄Cl, NH₄F, NH₄NO₃, etc.) produced in this neutralization will be soluble in the scrubber water, thus, they will not be present in the scrubber exit gas.



RECOMMENDATIONS

C-2

9. RECOMMENDATIONS

Based upon the data received by NASA, ICE calculated the potential emissions from the exhaust system. As a result of these calculations, it was determined that the OSHA limits would be exceeded under worst case operating conditions by the HCl gas, and under normal operating conditions by acetone and trichlorethylene. Thus, ICE recommends that an exhaust gas scrubber be installed.

Based upon the air flow requirements, ICE recommends that three DFCC23 scrubber modules or equivalent be utilized to handle the typical exhaust volume. These three scrubber modules will require a total of 15 gallons per minute (56,775 milliliters per minute of water)

In addition, ICE recommends that a hydrogen burn-off be installed on the present epitaxy reactor system. Calculations elsewhere in this report show that the scrubber is absolutely needed for epitaxial reactor, however, no provisions have been made to take an account of the hydrogen gas flow.

ICE also recommends that exhaust hoods or vent hoods be placed over the end of the CVD reactor to protect the room of unwanted gas flow during possible tube breakage.

It should be noted that the above calculations and recommendations are based on the planned conditions, as provided by NASA. These conclusions do not take into account added processing steps or new chemicals which might be added at a later date. It should be noted that some chemicals such as H_2SO_4 are close to the limits now, and any change in the rate can cause these materials to exceed OSHA limits.

If an exhaust gas scrubber is not used, ICE strongly recommends that the present exhaust vent be modified to a vertical position to release the gases above the roof line. In addition, the outlet should be at least six feet from any possible air intakes. Vents should also have some type of covering or traps, so heavy rain water will not wash down the stack, and create possible corrosive problems in the duct work.

It should be noted that in some areas the EPA requires measurements of contaminants at the exhaust stack. For example, semiconductor plants in Austin, Texas must measure pollutants at the exhaust stack outlet, thus, scrubbers would be necessary to meet EPA requirements. Other locations, such as Phoenix, Arizona are allowed to measure contaminants at the plant boundry, which does allow adequate dillution.

In reviewing this particular requirement, ICE found that there is no source of information in the industry regarding vapor pressures of mixed chemicals. This is necessary to provide and obtain accurate calculations of potential hazards. ICE made several assumptions in arriving at the necessary vapor pressures for the calculations listed in this report. It would be desirable to have experimental and calculated data confirmed, so that these vapor pressure values might be available to others in the industry as well as reinforcing our calculations.

APPENDIX

APPENDIX A

CHEMICAL SOLUTIONS USED IN PROCESSING

Several chemical solutions used in the processing of polysilicon-gate CMOS/SOS deep depletion circuits require that they be mixed by the processor. Some solutions cannot be readily found in the mixed form while others should be mixed immediately prior to use. All chemicals used in processing should be reagent grade or equivalent to prevent contamination of the wafers.

Sulfuric Acid-Nitric Acid Solution

2ml	H ₂ SO ₄	Sulfuric Acid (~98%)
1ml	HNO ₃	Nitric Acid (~70%)

Buffered Oxide Etchant

5g	NH ₄ F	Ammonium Fluoride-Crystal
2ml	HF	Hydrofluoric Acid (~49%)
8ml	H ₂ O	Water

Hydrofluoric Acid Solution

1ml	HF	Hydrofluoric Acid (~49%)
10ml	H ₂ O	Water

Jacobson's Etchant

25ml	H ₂ O	Water
5ml	HCl	Hydrochloric Acid (~37%)
5ml	HNO ₃	Nitric Acid (~70%)
1ml	H ₂ SO ₄	Sulfuric Acid (~98%)

APPENDIX A (concluded)Aluminum Etchant

25ml	H_3PO_4	Phosphoric Acid (~85%)
5ml	CH_3COOH	Acetic Acid - Glacial (~100%)
1ml	HNO_3	Nitric Acid (~70%)

Aluminum Compatible Photo Resist Remover

55g	H_2SO_4	Sulfuric Acid (~93%)
1g	CrO_3	Chromic Acid Anhydride-Crystal

Silicon Etchant

2g	KOH	Potassium Hydroxide-Crystal
2ml	$\text{CH}_2\text{OHCH}_2\text{CH}_3$	1-Propanol
7ml	H_2O	Water

Azeotropic Mixture for Gate Oxidation

113ml	HCl	Hydrochloric Acid (~37%)
110ml	H_2O	Water

APPENDIX B
ABBREVIATIONS

VOLUME

cf	Cubic Feet
cc	Cubic Centimeters
l	Liters
gal	Gallons
m ³	Cubic Meters

FLOW

cfm	Cubic Feet Per Minute
cc/min	Cubic Centimeters Per Minute
l/min	Liters Per Minute
m ³ /min	Cubic Meters Per Minute
gpm	Gallons Per Minute
lb/day	Pounds Per Day
g/min	Grams Per Minute
g/day	Grams Per Day

CONCENTRATION

ppm	Parts Per Million (volume basis)
mg/m ³	Miligrams Per Cubic Meter

MASS

g	Grams
mg	Miligrams
lb	Pounds
kg	Kilograms
mol	One Gram Molecular Weight

PRESSURE

tor	Milimeters of Mercury at 20°C
atm	Atmospheres (1 atm = 760 tor)

DENSITY

g/cc	Grams Per Cubic Centimeter
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APPENDIX C
CONSTANTS AND CONVERSION FACTORS

22.4	Volume of 1 gram molecular weight of gas (1 mol volume)
44.64	Mol volumes per cubic meter
162.6	Stoddard solvent, liquid volume to vapor volume conversion
142.1	Xylene solvent, liquid volume to vapor volume conversion
.0283	Cubic meters per cubic feet
28317	Cubic centimeters per cubic foot
.135	Diffusion and CVD exhaust dilution factor
154	Etch hood dilution factor
1.5	Total vent dilution factor
454	Grams per pound
.90	Specific gravity of xylene
.684	Specific gravity of stoddard solvent
.883	Specific gravity of n-butylacetate
760	Standard conditions atmospheric pressure in tor

APPENDIX D
MOLECULAR WEIGHT OF CHEMICALS

<u>Chemical</u>	<u>Symbol</u>	<u>Molecular Weight, g</u>
Phosphine	PH ₃	34.00
Diborane	B ₂ H ₆	27.67
Hydrogen Chloride	HCl	36.46
Ammonia	NH ₃	17.03
Dichlorosilane	SiH ₂ Cl ₂	101.01
Nitrous Oxide	N ₂ O	44.01
Ammonium Chloride	NH ₄ Cl	53.49
Hydrogen Fluoride	HF	20.01
Nitric Acid	HNO ₃	63.01
Sulfuric Acid	H ₂ SO ₄	98.08
Phosphoric Acid	H ₃ PO ₄	98.00
Acetic Acid	CH ₃ COOH	60.05
Acetone	---	58.08
Trichlorethylene	---	131.4
Propanol	---	60.11
Xylene	---	106.17
Stoddard Solvent	---	---
N-Butyl Acetate	---	116.16
Hydrogen	H ₂	2.00
Dilicon Tetrachloride	SiCl ₄	169.90
Arsine	AsH ₃	77.91
Silane	SiH ₄	32.09
Calcium Carbonate, (Limestone)	CaCO ₃	100.09

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EPIITAXY OPERATION EMISSIONS

AMMONIA (NH ₃)	SILICON GROWTH WITH SiCl ₄ SOURCE	SILICON GROWTH WITH SiH ₄ SOURCE	AMMONIA/ NITROUS OXIDE	HCl CLEANING	HCl ETCHING	OSHP LIMITS	PROBLEM AREAS	H ₂ O SOLUBILITY CC/CCl ₂ O
ppm mg/m ³ g/day Normal Case g/day Worst Case			500,000 330 228 456			50 35	*	89/100
HYDROGEN CHLORIDE (HCl)								
ppm mg/m ³ g/day Normal Case g/day Worst Case	387,000 631,000 7,420 14,800			750,000 1,221,000 733 1,470	200,000 324,000 8.12	5	*	82.3/100
NITROUS OXIDE (N ₂ O)								
ppm mg/m ³ g/day Normal Case g/day Worst Case			25,300 49,700 15.3 30.6			25(T)	*	130/100
DIBORANE (B ₂ H ₆)								
ppm mg/m ³ g/day Normal Case g/day Worst Case	1.29 1.55 .0048 .0096	1.29 1.55 .0048 .0096				.1 .1	*	DEC TO H ₂ BO ₃
PHOSPHINE (PH ₃)								
ppm mg/m ³ g/day Normal Case g/day Worst Case	1.29 1.90 .0006 .0012	1.29 1.90 .0006 .0012				.3 .4	*	.26/100
ARSINE (AsH ₃)								
ppm mg/m ³ g/day Normal Case g/day Worst Case	1.29 4.37 .0014 .0028	1.29 4.37 .0014 .0028				.05 .2	*	20/100

CVD AND DIFFUSION OPERATION EMISSIONS

	CVD OPERATION		DIFFUSION OPERATION		GROSS UNREACTED TOTAL OUTPUT		NET COMBINED OUTPUT MINIMUM REACTED MAXIMUM		NET OUTPUT WITH TOTAL EXHAUST DILUTION MINIMUM REACTED MAXIMUM		OSHA PROBLEM AREAS LIMITS						
	RUIN	CLEAN	RUIN	CLEAN	RUIN	CLEAN	3.14	6.28	3.14	0	3.14	0	3.14	0	424	0	50
AMMONIA (NH3)																	
ppm, Normal Case	3.14	11.8	3.14	17.7	3.14	17.7	3.14	6.28	3.14	0	3.14	0	3.14	0	424	0	50
ppm, Worst Case	6.28	23.5	6.28	41.2	6.28	41.2	6.28	12.56	6.28	0	6.28	0	6.28	0	848	0	50
mg/m3, Normal Case	2.39	9.59	2.39	17.7	2.39	17.7	2.39	4.78	2.39	0	2.39	0	2.39	0	323	0	35
mg/m3, Worst Case	4.78	19.2	4.78	35.4	4.78	35.4	4.78	9.56	4.78	0	4.78	0	4.78	0	645	0	35
g/day, Normal Case	87.8	374	87.8	1554	87.8	1554	87.8	1756	87.8	0	176	0	176	0	176	0	35
g/day, Worst Case	176	703	176	3108	176	3108	176	3512	176	0	351	0	351	0	351	0	35
HYDROGEN CHLORIDE																	
ppm, Normal Case	3.14	11.8	3.14	17.7	3.14	17.7	3.14	6.28	3.14	0	3.14	0	3.14	0	424	0	50
ppm, Worst Case	6.28	23.5	6.28	41.2	6.28	41.2	6.28	12.56	6.28	0	6.28	0	6.28	0	848	0	50
mg/m3, Normal Case	5.1	19.2	5.1	17.7	5.1	17.7	5.1	10.2	5.1	0	5.1	0	5.1	0	51	0	7
mg/m3, Worst Case	10.2	38.4	10.2	35.4	10.2	35.4	10.2	70.8	10.2	0	10.2	0	10.2	0	102	0	7
g/day, Normal Case	187	703	187	1554	187	1554	187	3512	187	0	351	0	351	0	351	0	7
g/day, Worst Case	374	1406	374	3108	374	3108	374	7032	374	0	703	0	703	0	703	0	7
AMMONIUM CHLORIDE																	
ppm, Normal Case	3.14	11.8	3.14	17.7	3.14	17.7	3.14	6.28	3.14	0	3.14	0	3.14	0	424	0	50
ppm, Worst Case	6.28	23.5	6.28	41.2	6.28	41.2	6.28	12.56	6.28	0	6.28	0	6.28	0	848	0	50
mg/m3, Normal Case	5.1	19.2	5.1	17.7	5.1	17.7	5.1	10.2	5.1	0	5.1	0	5.1	0	51	0	7
mg/m3, Worst Case	10.2	38.4	10.2	35.4	10.2	35.4	10.2	70.8	10.2	0	10.2	0	10.2	0	102	0	7
g/day, Normal Case	187	703	187	1554	187	1554	187	3512	187	0	351	0	351	0	351	0	7
g/day, Worst Case	374	1406	374	3108	374	3108	374	7032	374	0	703	0	703	0	703	0	7
NITROUS OXIDE (N2O)																	
ppm, Normal Case	3.92	15.7	3.92	15.7	3.92	15.7	3.92	7.84	3.92	0	3.92	0	3.92	0	49	0	5(Dust)
ppm, Worst Case	7.84	31.4	7.84	31.4	7.84	31.4	7.84	15.68	7.84	0	7.84	0	7.84	0	98	0	5(Dust)
mg/m3, Normal Case	7.7	31.4	7.7	31.4	7.7	31.4	7.7	15.4	7.7	0	7.7	0	7.7	0	77	0	5(Dust)
mg/m3, Worst Case	15.4	62.8	15.4	62.8	15.4	62.8	15.4	30.8	15.4	0	15.4	0	15.4	0	154	0	5(Dust)
g/day, Normal Case	282	1154	282	1154	282	1154	282	568	282	0	282	0	282	0	282	0	5(Dust)
g/day, Worst Case	564	2308	564	2308	564	2308	564	4716	564	0	564	0	564	0	564	0	5(Dust)
DIBORANE (B2H6)																	
ppm, Normal Case	.078	.314	.078	.314	.078	.314	.078	.156	.078	0	.078	0	.078	0	.078	0	1
ppm, Worst Case	.156	.628	.156	.628	.156	.628	.156	.312	.156	0	.156	0	.156	0	.156	0	1
mg/m3, Normal Case	.097	.396	.097	.396	.097	.396	.097	.194	.097	0	.097	0	.097	0	.097	0	1
mg/m3, Worst Case	.194	.792	.194	.792	.194	.792	.194	.388	.194	0	.194	0	.194	0	.194	0	1
g/day, Normal Case	140	568	140	568	140	568	140	282	140	0	140	0	140	0	140	0	1
g/day, Worst Case	279	1136	279	1136	279	1136	279	568	279	0	279	0	279	0	279	0	1
PHOSPHINE (PH3)																	
ppm, Normal Case	.078	.314	.078	.314	.078	.314	.078	.156	.078	0	.078	0	.078	0	.078	0	3
ppm, Worst Case	.156	.628	.156	.628	.156	.628	.156	.312	.156	0	.156	0	.156	0	.156	0	3
mg/m3, Normal Case	.119	.476	.119	.476	.119	.476	.119	.238	.119	0	.119	0	.119	0	.119	0	4
mg/m3, Worst Case	.238	.952	.238	.952	.238	.952	.238	.476	.238	0	.238	0	.238	0	.238	0	4
g/day, Normal Case	.171	.696	.171	.696	.171	.696	.171	.342	.171	0	.171	0	.171	0	.171	0	4
g/day, Worst Case	.343	1.392	.343	1.392	.343	1.392	.343	.686	.343	0	.343	0	.343	0	.343	0	4

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Figure 6

ETCH STATIONS, DIFFUSION AND CVD STATIONS, AND PHOTORESIST STATIONS
COMBINED TOTAL EMISSIONS FROM

ETCH FACILITY		HYDROFLUORIC ACID HF	HYDROCHLORIC ACID HCl	NITRIC ACID HNO ₃	SULFURIC ACID H ₂ SO ₄	PHOSPHORIC ACID H ₃ PO ₄	ACETIC ACID CH ₃ COOH	ACETONE	TRICHLOR ETHYLENE	PROPANOL	XYLENE	STANDARD SOLVENT	BUTYL ACETATE	AMMONIA NH ₃	AMMONIUM CHLORIDE NH ₄ Cl	NITROUS OXIDE N ₂ O	DIBORANE B ₂ H ₆	PH ^{PH} PH ₃
Normal Case		0.89	0.002	0.510	0.056	0.009	2.8	1139	399	45.4								
mg/m ³		0.79	0.004	1.74	0.037	7.6	2953	2953	2338	122								
q/day		145	732	318	144	6.77	1390	540,000	428,000	22,300								
CVD AND DIFFUSION FACILITY																		
Normal Case			2.39															
mg/m ³			3.89															
q/day			1054															
Worst Case																		
mg/m ³			5.56															
q/day			9.07															
2459																		
PHOTORESIST FACILITY																		
Normal Case																		
mg/m ³																		
q/day																		
Worst Case																		
mg/m ³																		
q/day																		
TOTAL FACILITY EXHAUST																		
Normal Case		0.89	2.39	0.510	0.056	0.009	2.8	1139	399	45.4	0.056	0.044	0.020	0.424	0.425	0.529	0.019	0.011
mg/m ³		0.79	3.89	1.74	0.037	7.6	2953	2953	2338	122	0.361	0.186	0.134	0.323	1.02	1.04	0.013	0.016
q/day		145	1054	318	144	6.77	1390	540,000	428,000	22,300	97.9	50.6	36.3	87.8	276	282	140	173
Worst Case																		
mg/m ³			5.56									31	14.8	0.848	0.853	1.06	0.021	0.021
q/day			9.07									130	92.2	0.645	2.04	2.08	0.026	0.032
2459												50.6	36.3	176	554	564	279	347
OSHA LIMITS																		
mg/m ³		3	5	2	1	10	1000	1000	100	200	100	200	150	50	25(Dust)	25(Tent)	0.1	0.3
Problem Areas		2	7	5	1	25	2400	535	535	500	435	1150	710	35	5(Dust)	0.1	0.4	0.4

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TOTAL MAXIMUM EMISSIONS FROM ETCH FACILITY

	HF ppm	HC1 mg/m ³	HNO ₃ ppm	H ₂ SO ₄ ppm	H ₃ PO ₄ ppm	CH ₃ COO ppm	ACETONE ppm	TRICHLOR- ETHYLENE ppm	PROPANOL mg/m ³
1. 10:1 HF @RT	0.26								
2. DI H ₂ O	0.23								
3. Jacobson Etch @RT									
4. P.R. Strip		0.004	0.005	0.002					
5. DI H ₂ O				0.02					
6. Aluminum Etch @RT									
7. H ₂ SO ₄ -HNO ₃ Clean @RT			0.005	0.001					
8. DI H ₂ O			0.13	0.082					
9. Acetone									
10. TCE									
11. Silicon Etch									
12. DI H ₂ O									
13. H ₃ PO ₄ @CRT									
14. 10:1 HF @RT									
15. DI H ₂ O									
16. P.R. Strip									
17. DI H ₂ O									
18. BOE @ 50°C									
TOTAL FACILITY	0.26	0.004	0.005	0.02	0.003		1139	399	45.4
OSHA							2953	2338	122
Human Exposure Limits (for 8 Hours)									
*Possible Substitute is 1,1,1-trichloroethane OSHA Limit	0.37	0.0002	0.510	0.056	0.009	2.8	1139	399	45.4
	0.89	0.004	1.743	0.785	0.037	7.6	2953	2338	122
	2.0	5.0	5.0	1.0	1.0	10	1000	100	500
	3.0	7.0	2.0	-	-	25	2400	535	200
								350	1900

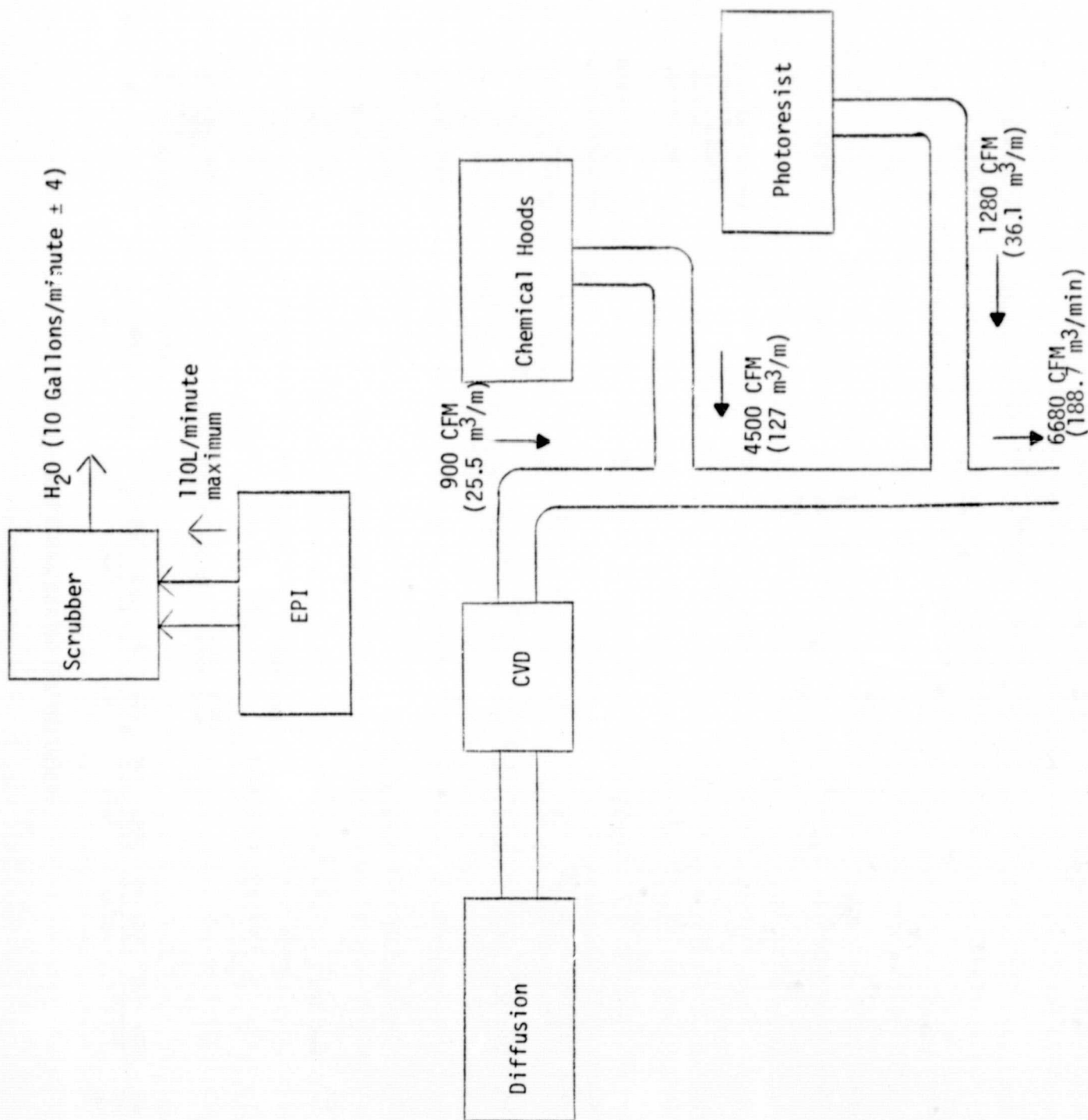
OSHA
Human Exposure Limits
(for 8 Hours)

EPA
NO₂ Emissions in
mg/m³/hr
Maximum Hourly
Average 24 hr
(From HNO₃ Etching)

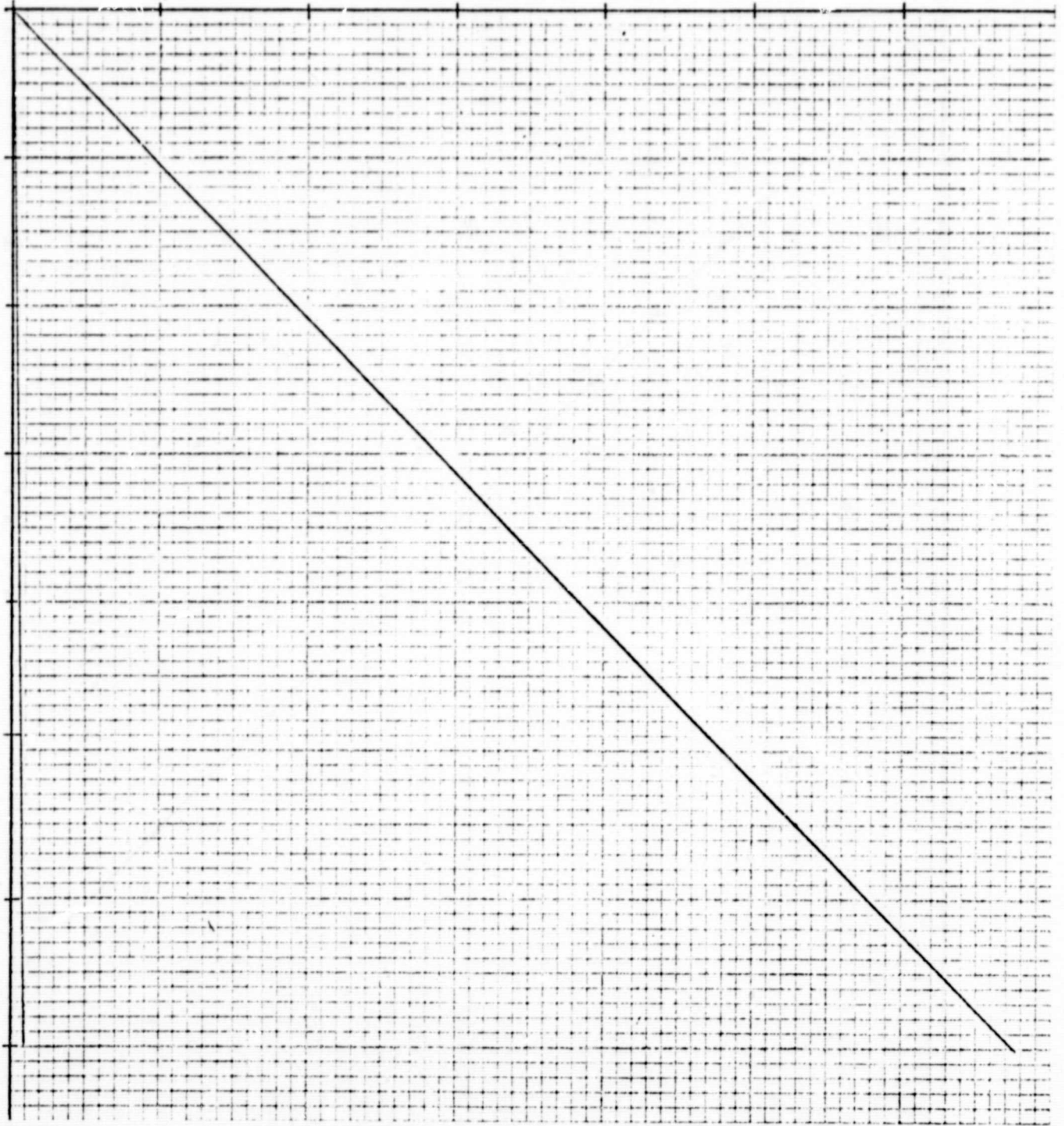
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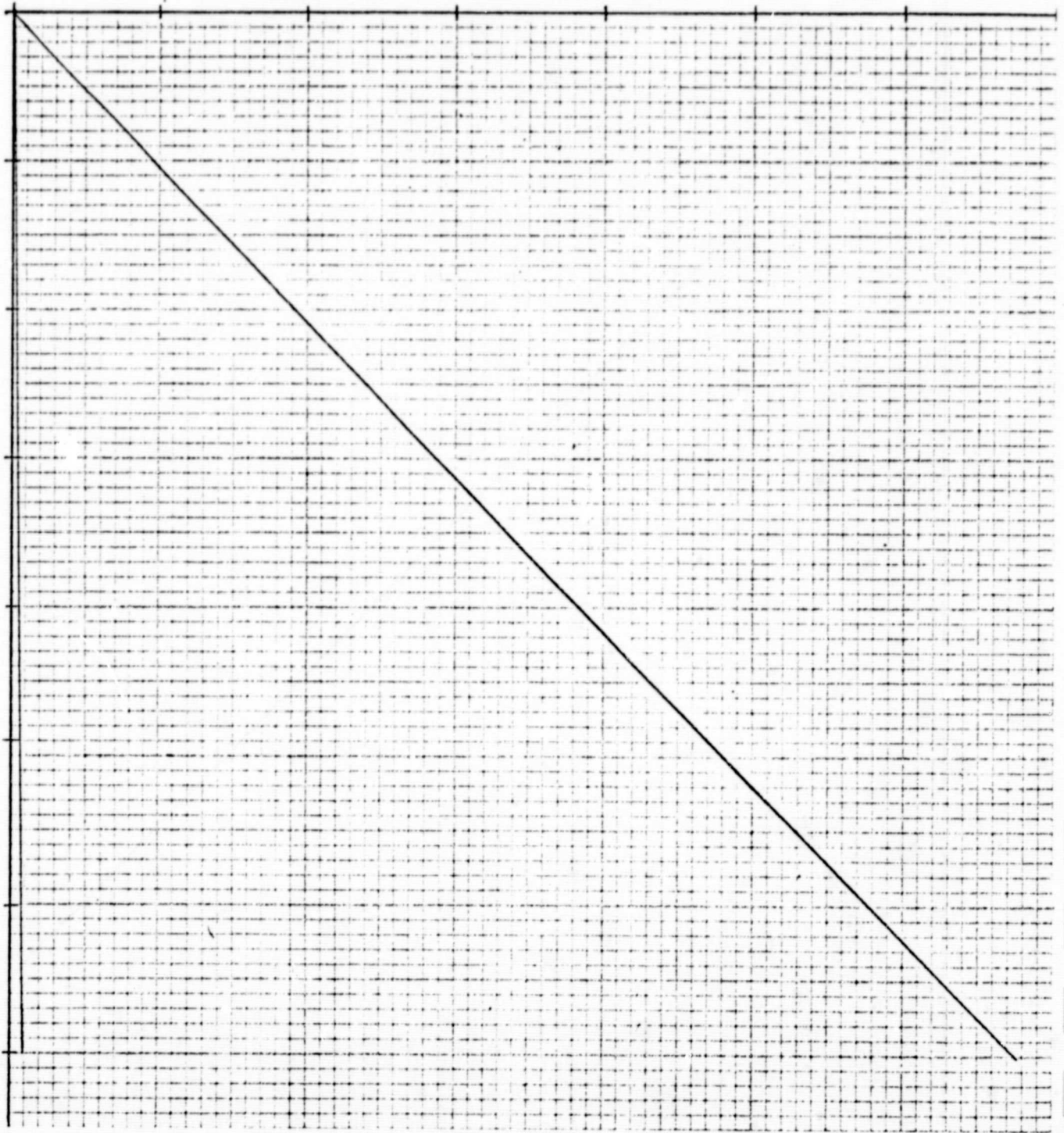
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4. SAFETY CHECKLISTS

OPERATIONS AND SAFETY CHECKLIST
GENERAL FACILITIES

THIS INCLUDES CONSIDERATIONS FOR THE FOLLOWING AREAS:

- A. DI WATER, COOLING WATER AND WASTE WATER SYSTEMS.
- B. COMPRESS GAS STORAGE, GAS AND VACUUM DISTRIBUTION SYSTEMS.
- C. VENT GAS SYSTEM.
- D. CHEMICAL STORAGE AND HANDLING, CHEMICAL ANALYSIS
- E. GLASSWARE CLEANING.
- F. ELECTRICAL AND PROCESS TESTING.

I-PRECONDITION/CALIBRATION STEPS

A. DI Water System, Cooling Water System, Water System Waste

- 1. Check or calibrate resistivity meters and indicators. ☐
- 2. Check or calibrate system pressure gauges, flow indicators and flow meters. ☐
- 3. Check operations of biological suppression system. ☐
- 4. Check for proper operation of solenoid valves, control valves and pressure relief devices. Check for corrosion or scale that can interface with proper operation. (Ref. 1). ☐
- 5. Check operations of chemical waste sewer operation. Check neutralization and pH monitor system. ☐
- 6. Check water quality from pre-treatment system. (Particulates, organics, dissolved gasses). ☐
- 7. Check resin regeneration reagent reservoir. Replenish as needed. . . ☐

CAUTION: Eye, limb and body protection
required when handling or exposed
to strong acids and bases. (Ref.
2, P. 11-14, P. 165-166).

- 8. Check operations of automatic regeneration cycle. (Ref. 1; Ref. 3). ☐
- 9. Check operations polisher tanks. (Ref. 1). ☐
- 10. Check operations of storage tank level control and circulating system. (Ref. 1). ☐
- 11. Check distribution system for leaks. ☐

B. Compressed Gas Storage, Gas and Vacuum Distribution System

1. Make sure gas cylinders are properly identified and mechanically secured in bulk storage and in manifold and on-site use. (Ref. 2, P. 10-42). ☐
2. Install cylinders in supply manifold. Inspect fittings and over-pressure relief. Check for leaks in fittings and manifold. . . ☐
3. Check operations of vacuum pump and vacuum distribution system. . . ☐
4. Check for leaks in total gas or vacuum system. ☐
5. Check operations of hazardous gas monitors. (Ref. 4). ☐
6. Check operations of combustible gas detectors. (Ref. 5). ☐
7. Check operations and readiness of Survivair self-contained breathing equipment. Replenish air supply as needed. (Ref. 2, P. 32-36). . . ☐

C. Vent Gas System

1. Check flow volume and draft pressure at various inlet stations. Balance system as needed. ☐
2. Check for structural integrity and loose joints in duct system. Check for leaks. ☐
3. Check for condensation in horizontal runs or natural traps. Drain if possible. ☐

CAUTION: Eye and hand protection required when handling or exposed to fluids that can be acidic. (Ref. 2, P. 11-14).

4. Check structural integrity of blowers and motors. ☐
5. Check proper operations of vent gas scrubbers. Replenish limestone beds as needed. ☐

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D. Chemical Storage and Handling Chemical Analysis

1. Make sure that the safe amounts of chemicals are in internal and external storage. (Ref. 2, P. 94-106). ☐
2. Make sure that solvents, acids, bases and oxidizers are all stored and handled separately. ☐
3. Check for venting or leaking containers. Remove or correct as needed. (Ref. 2, P. 11-14). ☐

CAUTION: Face and hand protection required when handling or exposed to acids, bases or solvents. (Ref. 2, P. 11-14).

4. Use care in dispensing, mixing or diluting chemicals. Avoid spills, contaminations, toxic vapors or inflammable vapors. (Ref. 2, P. 11-14, 94-106). ☐

CAUTION: Eye, face, and hand protection required when working with strong acids or bases. Extreme care is required in handling HF. Absolute integrity of hand protection is essential. (Ref. 2, P. 11-14, 159-160, 213-216). In case of acid splash or spill use safety shower or eye wash as needed. Neutralize and absorb spills to eliminate liquid hazard. Ventilate room to eliminate vapor hazard.

5. Always dilute acids by adding the required amount of DI water to the acid while stirring. Never add acid to water. Be alert for a temperature rise due to the possible heat of solution. ☐
6. Keep chemical container properly sealed as much as possible to avoid contamination. ☐

E. Glassware Cleaning

1. Check for proper operations of reactor tube, cleaning hood, exhaust vent, DI water flow, and waste water drain. ☐
2. Store dirty reactor tubes so as to avoid breakage and possible toxic vapor emissions. ☐

3. Use care in dispensing, using, and draining acid etches and cleaners. ☐

CAUTION: Eye, face, body and limb protection required when exposed to or working with HF/HNO₃ mixtures. (Ref. 2, P. 159-160, 213-216). Absolute integrity of hand protection is essential when exposed to HF.

4. Always handle dirty lab glassware as if it were contaminated with hazardous or toxic chemicals. ☐
5. Store cleaned glassware to avoid possible gaseous or particulate contamination. ☐
6. Check for chips or cracks. Repair and stress relieve as needed. Reclean and then properly store. ☐

F. Electrical and Process Test

1. Check main electric power supply. Check voltage regulation, ripple and proper phasing. Check operations of breakers. (Ref. 2, P. 79-81, 82-93). ☐
2. Check electric power supply at each piece of major equipment. Check conduit, outlets and breakers. ☐

CAUTION: Make sure all equipment is properly grounded. (Ref. 2, P. 82-93).

3. Check for proper operations of electrical test equipment. Verify integrity of grounding and shielding where needed. (Ref. 6). ☐
4. Check for proper probe operations. Replace probe points as needed. (Ref. 6). ☐
5. Calibrate electrical test equipment as needed. (Ref. 6). ☐
6. Check and calibrate power supplies used for electrical testing. . . . ☐

2-OPERATING/PROCESS STEPS

Operations of these general facilities can be done in the manual mode. The water systems, gas systems, vent systems, and test systems are normally operated in the automatic mode.

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3-NORMAL SHUT DOWN STEPS

A. DI Water System, Cooling Water System, Waste Water System.

1. Shut down automatic regeneration system. ☐
2. Switch off instrumentation and controls. ☐
3. Continue circulation system. ☐

If long term shut down (several weeks or more) is anticipated then these additional steps are needed.

4. If continued circulation with the biological suppression system operating cannot be maintained, then the total system (including resin bed, but excluding pretreater) should be filled with a 1% formaldehyde in DI water solution to prevent biological fouling of lines, equipment, and resin. ☐
5. Remove regenerating reagents. Return to bulk storage. ☐
6. Switch off main electric power supply. ☐
7. Shut down waste water treatment system. ☐

B. Compressed Gas Storage, Gas and Vacuum Distribution System.

1. Close cylinder valves on supply manifold. ☐
2. Switch off hazardous gas monitors. (Ref. 4). ☐
3. Switch off combustible gas detectors. (Ref. 5). ☐
4. Shut down vacuum system. ☐

If long term shut down (several days or more) is anticipated, then these additional steps are needed.

5. Vent hazardous or toxic gas systems. Purge with N₂. ☐
6. Vent N₂ gas system. ☐

C. Vent Gas System

1. Make sure all sources of toxic, hazardous, or flammable vapors have been removed from the various processing systems. ☐
2. Shut down vent gas system blowers. ☐
3. Shut down vent gas scrubbers. ☐

F. Electrical and Process Test

1. Switch off individual test modules. ☐
2. Check for electrical equipment defects such as shorts, insulation breaks, proper grounds. (Ref. 2, P. 79-93). ☐

Normal maintenance and preventative maintenance is done on equipment after normal shut down. (Ref. 3, Ref. 5, Ref. 6).

4-EMERGENCY SHUT DOWN STEPS

A. DI Water System, Cooling Water System, Waste Water System.

This can be caused by chemical problems, (reagent spills) electrical/mechanical problems (power outage, loss of water pressure, or pump, valve or solenoid failure) or fire in an adjacent area.

1. Activate fire extinguisher system if needed. ☐
2. Switch off main electrical power supply. ☐
3. Turn off circulation system. ☐
4. Drain and dispose of regeneration reagents. ☐
5. Shut down cooling water system. ☐
6. Shut down waste water neutralizing and monitoring system. ☐
7. Inventory extent of damage. ☐

B. Compressed Gas Storage, Gas and Vacuum Distribution Systems.

This can be caused by toxic, hazardous or flammable gas leak, fire, over temperature or over pressure conditions or electrical/mechanical problems.

- Activate fire extinguisher system if needed. ☐
1. Close valves on leaking cylinders or leaking manifold and fittings. . ☐
 2. (Ref. 2, P. 37-42).

CAUTION: If vent gas system is shut-down and process gas cannot be safely turned off, then enter room only with self-contained breathing equipment to extinguish fire or close valves. (Ref. 2, P. 32-36, Ref. 7).

3. Shut down vent gas system. Shut down vent gas scrubber. ☐
4. Shut down N₂ gas system. ☐

5. Shut down vacuum systems. ☐
6. Switch off main AC electric power. ☐
7. Force ventilate room. Test for toxic or flammable gasses. (Ref. 4, Ref. 5). ☐
8. Inventory extent of damage. ☐

C. Vent Gas System

This can be caused by fire or electrical/mechanical problems. ☐

1. Shut down vent system when any fire occurs. An operating vent system can drain flames into an unaccessible and thus uncontrollable area. ☐
2. Shut down or dispose of sources of hazardous, toxic or flammable vapors. ☐

CAUTION: When vent gas system is shut down and process gasses cannot be safely turned off, then enter rooms only with self-contained breathing equipment. (Ref. 2, P. 32-36, Ref. 7).

3. Shut down vent gas scrubber. ☐
4. Shut down N₂ gas system. ☐
5. Switch off main AC electric power. ☐
6. Force ventilate rooms. Test for toxic or flammable gasses. ☐
7. Inventory extent of damage. ☐

D. Chemical Storage and Handling, Chemical Analysis.

This can be caused by a fire or damaged, leaking, or venting containers.

1. Activate fire extinguisher system if needed. ☐
2. Remove and dispose of source of venting or leaking chemicals, acids, bases or solvents. ☐

CAUTION: Eye, face and hand protection required when handling or exposed to strong acids and bases or solvents. (Ref. 2, P. 11-14, 94-106.

3. Check for toxic or hazardous gasses produced by thermal decomposition of chemicals exposed to a fire. ☐
4. Check for toxic or hazardous gasses produced by interaction of chemical or solvent from broken containers. ☐
5. Force ventilate room. Test for toxic or flammable gasses. (Ref. 4, Ref. 5). ☐
6. Inventory extent of damage. ☐

E. Glassware Cleaning

This can be caused by fire in adjacent area, major acid spill or mechanical problem.

1. Drain or dispose of acid etch solutions and cleaners. ☐

CAUTION: Eye, face, body, and limb protection required when handling or exposed to HF/HNO₃ mixtures. (Ref. 2, P. 159-160, 213-216).

2. Be careful for acid splash or broken glassware. ☐
3. Switch off main AC electric power. ☐
4. Over temperature of acid etches can cause production of toxic vapors. If this occurs then force ventilate room and remove source. ☐

CAUTION: If vent gas system is shut down and toxic gasses are present, then enter room only with self-contained breathing equipment. (Ref. 2, P. 32-36, Ref. 7).

5. Neutralize and absorb spills to eliminate liquid hazards. ☐
6. Inventory extent of damage. ☐

F. Electrical and Process Testing.

This can be caused by power outages, shorts, and mechanical/electrical problems with switches, relays, power supplies.

1. Switch off individual equipment modules. ☐

CAUTION: Make sure all electrical equipment is properly de-energized. Faulty switches or breakers can fail to switch off. (Ref. 2, P. 79-81).

2. Turn off N₂ or vacuum supply to test modules. ☐
3. Inventory extent of damage. ☐

5-EMERGENCY SHUT DOWN, CLEAN UP, INSPECTION AND REPAIR STEPS

Most of these steps are applicable to all of the General Facilities Areas.

1. Make sure main AC electrical power is switched off. (Ref. 2, P. 79-81). ☐
2. Clean up any fire extinguisher, chemical splash or fire damage on equipment. ☐

CAUTION: Eye and hand protection required when cleaning splashes of unknown origin. Handle as if it were a strong acid base or solvent. (Ref. 2, P. 11-14).

3. Inspect/test and repair any electric cable or insulation damage. . . ☐

CAUTION: Make sure all equipment is properly grounded. Make sure there are no electrical shorts. (Ref. 2, 79-93).

4. Selectively switch on electric power to each piece of equipment. . . . ☐
Check for proper reaction.
5. Inspect, test and repair as needed the total vent system and vent gas scrubber. ☐
6. Inspect and test operations of toxic gas monitor and combustible gas detector. (Ref. 4, Ref. 5). ☐
7. Check for broken glassware. Discard or repair and clean as required. ☐
8. Repair damage to fitting and relief devices on gas cylinder and manifolds. Pressure test as needed. (Ref. 2, P. 37-46). ☐
9. Do required maintenance on each piece of equipment. (Ref. 3, Ref. 6). ☐
10. When system check and required maintenance is completed, then either go to normal shut down or to Precondition/Calibration steps as needed. ☐

6-REFERENCES

1. DI Water System, Ion Exchnage Resin Regeneration Routine. MSFC 1979.
2. Safety and Environmental Health Standards, MM 1700. 4B, MSFC, October 15, 1974.
3. Operations and Maintenance Manual. Two Bed Deionization System.
4. Instruction and Maintenance Manual, Matheson Arsine/Phosphine Monitor. Matheson Gas Products.
5. Instruction Manual for Enmet Hazardous Gas Monitor/Alarm. Enmet Corporation.
6. Operations and Maintenance Manual In-process Automatic Test Equipment.
7. Instruction Manual, Survivair, 30-Minute Unit, September 1977, Survivair Inc.

OPERATION AND SAFETY CHECKLIST
VENT GAS SCRUBBER

EMERGENCY SHUTDOWN PROCEDURE

1. Activate fire extinguisher system if needed ☐
2. Evacuate work area if excessive toxic, corrosive or flammable gas is detected (Ref. 2, P. 720) ☐
3. Shut-down process gas sources (EPI, Diffusion, CVD Etch). . . ☐
4. Turn off electric power to scrubber ☐
5. Turn off water supply to scrubber ☐

Clean Up After Emergency Shut-Down

1. Clean work area to assure that any toxic, corrosive or explosive gas residue is below safe limits. If excessive residue is indicated; continue venting area until safe levels are reached before starting clean up. (Ref. 2, P. 720) ☐
2. Make sure final drain is working properly ☐
3. If limestone bed is plugged or depleted then drain water and replenish reagent. ☐
4. Drain scrubber water into limestone bed ☐

Caution:

Water may contain acid residue. Use gloves, face mask, and lab coat. Neutralize and dilute any spills to drain. (Ref. 1, P.3; Ref 2, P. 11 & 12)

5. Check integrity of vent duct system by leak testing ☐
6. Check integrity of scrubber module for liquid and gas leaks. . ☐

OPERATION

Preconditioning Steps

1. Switch on electric supply ☐
2. Turn on water supply, set pressure regulator to 20 PSI.
(Ref. 1, P.2) ☐
3. Remove 2 scrubber lids. ☐

Caution:

Possible acid water residue.
Use gloves, face mask and
lab coat. (Ref 2, P. 11 & 12.)

4. Check for proper operation of spray heads (Ref. 1, P. 2). ☐
5. Check that demister is not plugged. ☐
6. Replace scrubber lids. Check for seal integrity. ☐
7. Turn on blower. Check for correct rotation, speed and volume flow.
Check mechanical integrity. (Belts, pulleys, mounts, motor arching
or overheating). ☐
8. Check liquid level and presence of agitation thru view ports.
(Ref. 1, P. 2 & 3). ☐
9. Check for lid seal leaks, vent duct leaks, and liquid leaks ☐
10. Check for proper flow from scrubber into limestone bed and from bed
to final drain ☐
11. Check limestone bed level. Replenish if necessary. ☐
12. Check for proper air flow into final vent ☐
13. Establish equilibrium air and water flow for 45 minutes before
introducing vent gasses. (Ref. 1, P. 3) ☐

OPERATION

Operating Steps

1. Make sure precondition steps and condition have been achieved ☐
2. Check for lid seal and ducts for gas leaks and scrubber unit and piping for liquid leaks ☐
 - a. Small or non-hazardous leaks should be noted for repair and maintenance. (Ref. 1, P. 3) ☐
 - b. Large or catastrophic leaks should be handled emergency shut down.

CAUTION:

All gas leaks should be treated as toxic and all liquid leaks as acid.

3. Check for plugged spray heads (Ref. 1, P. 3) ☐
4. Make sure demister is not plugged (Ref. 1, P. 3).. ☐
5. Check for plugged drain to sanitary sewer. ☐
6. Maintain appropriate level in limestone bed. ☐
7. Test gas effluent for acceptable level of toxic gases (Ref. 3, P. 720) ☐
8. Test liquid effluent for pH from 6.0 to 9.0. Also check for As, B, F, concentration (Ref. 4, P. 1 & 2).. ☐

Normal Shut-Down

1. Shut-down process gas venting. Close process gas cylinders. Keep vent gas blower on. ☐
2. Maintain air and water flow for 15 minutes to purge remaining gas and liquid contaminants. ☐
3. Shut off blower and water supply ☐
4. Drain scrubber and limestone bed ☐
5. Turn off electric supply ☐

OPERATION

Emergency Shut-Down

There are three categories of problems that can require emergency shut-down. They are:

1. Ducting Problem. Leak or rupture (H_2 explosion) in vent duct to scrubber.
2. Scrubber Problem. Abnormal high vent gas flow, loss of blower, loss of water, massive leak or loss of scrubber seal, ruptured scrubber, plugged nozzles or plugged drain.
3. Limestone Bed and Drain Problems. Plugged (overflowing) or channeling (no neutralizing) bed, depleted bed, plugged final drain.

APPENDIX

References

1. Instruction Manual, No. IS20-78, Ducon Fumatron Scrubber
2. Safety and Environmental Health Standards, Marshal Manual MM 1700. 4B, July 1, 1976
3. Handbook of Laboratory Safety, Second Edition Chemical Hazard Information, CRC Publishing Co., 1976.
4. Memo to J. Scrip From J. Adamson, EPI Reactor System, Bldg. 4487, November 17, 1977.

OPERATION AND SAFETY CHECKLIST
CHEMICAL VAPOR DEPOSITION

EMERGENCY SHUT-DOWN
STEPS

Chemical Problem Shut-Down

This can be caused by reactive gas explosion or fire, large gas system leaks, gas flow from process tube (flange leak, crack, rupture), or vent system failure.

1. Activate fire extinguisher system if needed. ☐
2. Close valves on reactive gas cylinder ☐

CAUTION:

If vent system is not working and reactive gas cylinder valves cannot be closed, then enter room only with self-contained air breathing equipment to extinguish fire or close valves. (Ref 8).

3. Shut off CVD main electric supply at C180 Distribution Panel (Ref 1) ☐
4. Shut off N₂ supply to equipment (Ref. 1, Sec. 2.4, 6.4) ☐
5. Force ventilate room, test for toxic gas residue ☐
6. Switch off individual pieces of equipment. (Ref. 1, Sec. 1.3 P 2 & 3; Ref. 5). ☐
7. Inventory extent of damage. ☐

Electrical Problem Shut-Down

This can be caused by power outage, voltage excursions, shorts, damage to wire and insulation, and defects in electrical equipment (motors, solenoids, etc.).

1. Isolate and switch off vacuum module. (Ref. 1, Sec. 1.3 P. 3; 6.2 P 20; Ref 5). ☐
2. Isolate and switch off furnace (Ref. 1, Sec. 1.3 P. 2 & 3; Ref. 5) ☐
3. Isolate and switch off gas system (Ref. 1, Sec. 1.3 P 2 & 3; Ref. 5). ☐

4. Shut down load station
(Ref. 1, Sec. 1.3, P 2; Ref. 5) ☐
5. Shut down up-stream computer
(Ref. 1, Sec. 1.3, P. 3; Ref. 5). ☐
6. Shut down monitrol (Ref. 1, Sec. 1.3, P. 2; Ref. 5) ☐
7. Check equipment for possible electric shock ☐

Mechanical Problem Shut-Down

This can be caused by malfunctions on mechanical equipment, handling mechanisms, instruments and meters, control valves and pressure regulators.

1. Shut-down reactive gas system
(Ref. 1, Sec. 5.2, P. 17, Fig. 6 & 7).. ☐
2. Shut-down vacuum module system
(Ref. 1, Sec. 1.3, P. 3; 6.2, P. 20; Ref. 5). ☐
3. Shut-down furnace (Ref. 1, Sec. 1.3, P. 2 & 3,,; Ref. 5) . . ☐
4. Shut-down load station
(Ref. 1, Sec. 1.3, P. 2; Ref. 5). ☐
5. Shut-down up-stream computer
(Ref. 1, Sec. 1.3, P. 3; Ref. 5). ☐
6. Shut-down monitrol (Ref. 1, Sec. 1.3, P. 2; Ref.5).. . . . ☐
7. Inspect for equipment defects. ☐

EMERGENCY SHUT-DOWN - CLEAN-UP, INSPECTION AND REPAIR STEPS

Resulting from chemical problems

1. Make sure electrical power is turned off
(Ref. 7, Position 24).. . . . ☐
2. Vacuum-up dry extinguisher power, mop up liquid ☐
3. Wipe equipment, gages, meter faces with detergent
water (Ref. 4, Sec. IV, P. 8). ☐
4. Inspect/test and repair electrical wiring and insulating
damage. Make sure all equipment is properly grounded.. . . ☐
5. Selectively switch on all equipment electric power for
testing. (Ref. 1, Sec. 1.3, P 2 & 3; Ref. 5).. . . . ☐
6. Clean vent system, test for correct flow. ☐

1 - PRECONDITIONING/CALIBRATION STEPS

Utilities and Gasses

1. Turn on N₂, set pressure regulator at 80 PSIG, and set flow rate to wafer track, load station and vacuum module (Ref. 1, Sec. 2.4, P 10, S. 4, P. 22) ☐
2. Process reactive gas lines hooked up to panel. Purge gas lines and manifold with N₂ (Ref. 1, Sec. 5.1, P. 16, 5.2, P. 16) (Limit pressure to <50 PSIG) ☐
3. Electric power lines plugged into proper outlets. ☐

Caution:

Make sure all equipment
is properly grounded.

Equipment Check

1. Check proper operation of total vent gas system (Ref. 1, Sec. 6.2, P. 20; Fig. 6 & 7) ☐
2. Check proper operation of total vacuum module system. (Ref. 1, Sec. 6.2, P. 20; Fig. 8) ☐
3. Check oil level in vacuum pump, add if needed (Ref. 2, Sec. 2.2). ☐
4. Check and replace as needed filters on N₂ lines ☐
5. Pressure test process gas system when leak is suspected. After test, vent pressure and open individual gas cylinders. (Ref. 1, Sec. 5.1, P. 16) ☐
6. Check operations of pressure regulators, solenoid and control valves on gas system, wafer handling system and vacuum system (Ref. 1, Sec. 5.7, 5.8, P. 18; 6.2, 6.4, P. 22; Fig. 4, 6 & 7). ☐
7. Calibrate thermocouple circuits, and vacuum gages (Ref. 1, Sec. 6.2, 6.3, Ref. 4, Sec. III, P.7). ☐
8. Check/set temperature, pressure, pressure limits flow/ conditions required for process. Pages 17 & 18) ☐
9. Purge vacuum pump to exhaust with N₂ (Ref. 1, Sec. 6.4 E. P. 23). ☐
10. Turn Vacuum Pump on. (Ref. 1, Sec. 6.2 P. 20). ☐
11. Pump down vacuum system. Check for acceptable leak rate of rise. Repressure with N₂. (Ref. 1, Sec. 6.2, P. 20 & 21; Sec. 6.4 E, P. 23). ☐

Initializing System

1. Establish initial conditions (Ref. 1, Sec. 1.2, P.1, Ref. 5) ☐
2. Start up wafer track (Ref. 5) ☐
3. Switch on monitrol. Load system, control point
table and process tapes. Select manual/auto mode
(Ref. 1, Sec. 1.3 A, P.2; Ref. 5) ☐
4. Switch on load station. Select manual/auto mode
(Ref. 1, Sec. 1-3 B, P.2; Ref. 5). ☐
5. Switch on vacuum pump. Select manual/auto mode.
(Ref. 1, Sec. 6.2 P. 20; Ref. 5). ☐
6. Carefully load wafers into empty carrier on BT-1 ☐

2 - OPERATING/PROCESS STEPS

Operations of the system are done in either the automatic or manual mode.

1. Check to make sure initializing conditions have been set. ☐
(Ref. 1, Sec. 1.2, P. 1; Ref. 5).
2. Start up-stream computer (Ref. 1, Sec. 1.3A, 4.0, P. 14). . ☐
3. Start monitrol computer (Ref. 1, Sec. 1.3, P. 3;, P. 2.). . ☐
4. Automatic Mode
Operate total system in remote/auto mode
(Ref. 1, Sec. 1.3, B, P.2). ☐
5. Manual Mode
Operate wafer loading system in local/manual mode
(Ref. 1, Sec. 3.1, P. 13; Ref 2.0, P. 11 & 3.0 P. 11) . . . ☐
6. Operate vacuum module system in local/manual mode
(Ref. 1, Sec. 6.1, P. 20).. ☐

7. Clean and check operation of reactive gas regulators;
solenoid valves and flow meters.
Purge liens and manifold (Ref. 1, Sec. 5-2, P. 16 & 17;
Ref. 5)..... ☐
8. Pressure/leak test gas system
(Ref. 1, Sec. 5.1, P. 17). ☐
9. Clean vacuum pump, check oil level and contamination, and
check operations. (Ref. 1, Sec. 6.3, P. 20; Ref. 2, Sec. 3.1,
3.2, P. 6; Ref 5)..... ☐
10. Remove, clean and reinstall process tubes.
Repair/replace damaged components
(Ref. 1, Sec. 7.1, 7.2, P. 24). ☐
11. Leak test process tube/vacuum system
(Ref. 1, Sec. 7.3, P. 25) ☐
12. Check operation of safety interlock on vacuum module.
(Ref. 1, Sec. 6.4, P. 22) ☐
13. Check furnace heat-up and control. (Ref. 5). ☐
14. Check operations of boat puller/pusher
(Ref. 1, Sec. 2.3, P. 9; Ref. 6). ☐
15. Check operations of load station through a complete
cycle (Ref. 1, Sec. 2.0, P. 4; Sec. 2.1, P. 5;
Fig. 2; Ref. 6)..... ☐
16. Check operations of up-stream controller
(Ref. 1, Sec. 4.0, P. 14 & 15; Ref. 5). ☐
17. Check operations of monitrol
(Ref. 1, Sec. 3.0, P. 11 & 12; Ref. 5). ☐
18. When system checks are complete, then either go to
normal shut-down steps or to precondition/calibration
steps as needed. (Ref. 5). ☐

3 - NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic or manual mode.
All wafers are removed from system.

1. Establish final conditions (deposition completed) ☐
2. Purge vacuum pump to exhaust with N₂.
 (Ref. 1, Sec. 6.4). ☐
3. Switch off vacuum pump (Ref. 1, Sec. 6.2, P. 20;
 Sec. 6.4 B,C,D, P. 22). ☐
4. Switch off up-stream computer ☐
5. Unload tapes (Ref. 1, Sec. 1.3, P. 2).
6. Switch off monitrol (Ref. 1, Sec. 1.3, 2.1, P. 2) ☐
7. Close valves on reactive gas cylinders. Purge lines and
 manifold with N₂ (Ref. 1, Sec. 5.2, P. 16). ☐
8. Turn off N₂ and dry air supply
 (Ref. 1, Sec. 2.4, P. 10).. . . . ☐
9. Switch off main electric supply (Ref. 7, position 24).. . . ☐

The need for maintenance is determined by inspection after normal shut-down.

1. Check and clean process tube (Ref. 1, Sec. 7.1, 7.2, P. 24).. ☐
2. Switch on electric supply to equipment under test.. . . . ☐
3. Leak test vacuum system (Ref. 1, Sec. 7.3, P. 25).. . . . ☐
4. Check vacuum pump oil for level and contamination
 (Ref. 2, Sec. 3.1, 3.2).. . . . ☐
5. Clean foreline trap. (Ref. 1, Fig. 8).. . . . ☐
6. Replace gas filers as needed ☐
7. Check seals and lubricate vacuum gate valves
 (Ref. 3, Sec. 1., P. 1).. . . . ☐
8. Clean and lubricate mechanical equipment as needed. . . . ☐
9. Check vent system equipment and flow. (Ref. 1, Fig. 8). . . ☐

6 - APPENDIX

References

1. Automatic Vacuum Chemical Deposition and Furnace Control System Operation Manual, DPS-1013, April 21, 1977 - Tylan Corporation.
2. Primary Vacuum Rotary Pump, Instructions for Starting and Maintenance, CIT-Alcatel
3. SVB Series, High Vacuum Gate Valves Operation and Maintenance, Torr Vacuum Products.
4. Thermocouple Vacuum Gage Controller Operating Instruction, Varian Lexington Vacuum Division
5. CVD System Routine (CVD 9 & 10)
6. CVD Reactor Automatic Loading Station Sequence (CVD 7 & 8)
7. Photograph Of RM C-180 Power Distribution Panel
8. Survivair 30-Minute Units Instruction Manual, September 1977, Survivair Division, U.S. Divers Co.

REFERENCE 5

CVD SYSTEM ROUTINE

1. Furnaces are energized by switches on controllers
2. Doping systems are turned on by switches on plug strips (1 per cabinet) at the bottom of the cabinets. Lights at top of cabinets have separate switches.

A. FURNACE (COMPUTER MONITOR)

1. Turn on Plug Strips
2. Turn Monitor ON
3. Sequence Control Switch to Manual Mode
4. Verify Tube off lights lit (2 tubes)
5. Verify all "VALVES OFF" Indicators ON.
6. Verify all switches in "AUTO MODE" on I/O Module.

B. LOAD STATION

1. Turn on Load Station Breaker at end of station.
2. Turn on Limiter Flow Fan and Load Station Lights
3. Turn on Load Station Power (under air track)
4. Turn on Buffer - T Power Switches (4)
5. Verify N₂ Regulator set at 20 PSIG for Buffer T and TRAM track.
6. Set TRAM TRACK N₂ regulator at 6-7 PSIE.

C. VACUUM SYSTEM

1. Verify power plug into vacuum Pump Frame
2. Turn on Vacuum Pump Power Switches -2 on Monitor & 2 on Pump Panel.
3. Set to Manual Mode Pump (PUSH Switch in).
4. Set pump and Vent Switches to closed position (Push Button Switch out).

D. FURNACE REACTOR

UPPER TUBE - #1

LOWER TUBE - #2

1. In Temperature Controller Drawer, Place Switches in "Manual Mode".
2. Place Thumb Wheel Switches to desired temperature.
3. Close Furnace Tube Main Element Breaker
4. Set Deviation Indicator to desired tolerance points and energize.
5. Verify station exhaust cooling Fan is ON.
6. Temperature profile process tube.
7. #1 (Upper) Tube used for SiN₄ & Poly Si.
#2 (Lower) Tube used for Doped & Undoped SiO₂ (BzH₆ + PH₃)
Monitor Designation
Tube #1 - Gold
Tube #2 - Red

E. MONITROL

1. Verify all switches in Auto Mode (UP) on I/O Modules
2. Verify all output Lights for valves are off.
3. Open Ball valves for each "Flow Loop" in source cabinet.
ON, OFF

F. Furnace Ready for Loading and Processing when temperature is stabilized.

REFERENCE 6

DIFFUSION FURNACE AND CVD REACTOR AUTOMATIC LOADING STATION SEQUENCE

A. Loading Sequence

1. Push BT (BOAT) request Switch (X) on Monitor.
2. Horizontal (H) Boat Pusher (BP)
Pulls paddle from tube. Out H-LIMIT SWITCH (LS) Actuated
H-BP and Paddle stops.
3. Claw opens-vertical (V) BP descends
4. SELECTED TUBE POSITION (STP) LS is Actuated
CLAS POSITION Switch (CPS) is activated.
VBP Stops
Claw closes
VBP and Boat Ascends
5. CPS - deactivated
HBP moves toward tube
CPS Activated again
HBP stops
VBP moving up
Sequence 5 repeated until HBP actuates HORIZONTAL Middle Position Switch (HMPS).
6. HMPS function:
increases VBP ACCENT RATE
HBP keyed to a constant push rate toward tube.
7. VBP stops when upper LS is activated.
8. HBP stops when in LS is activated.
9. VBP descends
Reaches Buffer T (BT) PS
V RATE decreases
Boat is placed in BT
Boat handle activates claw LS
VBP STOPS
10. The claw opens
BT carriage and Boat descends
Descends until bottom limit is reached
11. Wafers are transferred between BT's
After wafers are loaded. (BT Loaded Command)
12. Carriage and Boat has ascended to claw position
13. Claw closes
claw and boat ascends to VBP UPPER LS
claw and boat stop
14. HBP pulls paddle from tube
HMPS activated stops paddle
15. VBP descends slow rate
boat engages paddle
CPS activated VBP stops
HBP moves paddle out very slow rate
CB5 deactivates VBP descends until CP5 activation again stop VBP
16. VBP action continues until either
 - (1) HBP Activities out LS and STOPS
Tube position switch
Cls actuated
 - (2) VBP activates VLS and stops
HBP stops at the same time

17. Claw opens
VBP travels to top limit position
18. HBP moves boat into tube process position
H in P5 actuated.

B. Unloading Sequence

1. Push Process End Switch (X) on Monitor
2. Sequence order and description
 - a. A2
 - b. A3
 - c. A4
 - d. A5
 - e. A6
 - f. A7
 - g. A8
 - h. A9
 - i. A10
3. BT proximity sensor is activated by the wafer presence and sends wafers out on exit air track on a 4 second time interval until boat is empty and bottom limit is reached, and carriage ascends to top position.
4.
 - a. 13
 - a. 14
 - a. 15.
 - a. 16.
 - a. 17.
 - a. 18.

OPERATION AND SAFETY CHECKLIST

EPITAXIAL DEPOSITION

I. PRECONDITIONING/CALIBRATION STEPS

Utilities and Gasses

1. Turn on AC electric power if needed (Ref 1, Sec 3.2, p 3-1; Ref 2, switch 1,2,3,4 & 5)..... ☐

CAUTION: Make sure that AC power is connected to proper line voltage. Make sure that reactor module is properly grounded. Electric power should be normally left on for the reactor light, electronic components and RF chamber air blower (Ref 1, sec 7.8, p 2-14; Sec 3.2A, p 3-1).

2. Turn on exhaust system and exhaust scrubber. Check for clear lines and proper operation (Ref 1, sec 2.8, p 2-14, 2-15)..... ☐
3. Turn on raw water supply to RF generator heat exchanger. Check water quality, inlet temperature (55-60°F) and room dew point (Ref 1, sec 2.3, p 2-3, 2-4, 2-5; Ref 7, sec 2.3, p 13 & 14, sec 4.1, p 18)..... ☐
4. Turn on main N₂ valve at incoming gas control system panel if needed (Ref 1, sec 3.2B, p 3-1; Ref 3, valve Main N₂)..... ☐

CAUTION: The N₂ valve should remain on at all times (Ref 1, sec 3.2, p 3-1).

5. Set main N₂ gas pressure regulator at 20-30 psi (Ref 1, sec 3.2, p 3-1; Ref 3, valve Main N₂ and regulator Main N₂)..... ☐

6. Set N₂ purge gas pressure regulator at 10-15 psi (Ref 1, sec 2.6, p 2-8,2-9; sec 3.2, p 3-3, 3-5; Ref 3, regulator Purge N₂)..... ☐
7. Set fluidic interlock N₂ gas pressure regulator at 10 psi (Ref 1, sec 3.2, p 3-1; Ref 2, regulator Fluidic N₂)..... ☐
8. Turn on hydrogen burn-off system..... ☐
9. Turn on main H₂ valve at incoming gas control system panel (Ref 1, sec 3.2D, p 3-5; Ref 3 valve Main H₂)..... ☐
10. Set main H₂ gas pressure regulator at 20-30 psi (Ref 1, sec 3.2D, p 3-5; Ref 3 regulator Main H₂)..... ☐
11. Set H₂ purge gas pressure regulator at 10-15 psi (Ref 3, regulator Purge H₂)..... ☐

Equipment Check

1. Check reactor tube for structural integrity and cleanliness. Repair and/or replace and clean as needed (Ref 1, sec 4.3, p 4-2, 4-3, 4-4, 4-5)..... ☐

CAUTION: Do not touch quartz tube with bare hands. Use gloves.
Eye, face and hand protection are required when cleaning tube with HF/HNO₃ acid mixtures (Ref 1, sec 4.3, p 4-3).

2. Check reactor door gasket for gas-tight seal. (Ref 1, sec 3.1, p 3-1)..... ☐
3. Check that susceptors are clean and that build-up is not excessive. Clean as needed (Ref 1, sec 3.1, p 3-1, sec 4.2, p 4-1, 4-2)..... ☐
4. Check that pyrometers are aligned and clean (Ref 1, sec 4.15, p 4-11)..... ☐
5. Check operations of N₂ purge system. Flows should be 50-65 l/min. Graphic panel Purge N₂ and reactor control unit POST N₂ indicator lights on (Ref 4, switch LN and switch RN, flowmeter A; Purge N₂; Ref 5, POST N₂ switch)..... ☐
6. Check operations of hazardous gas monitor (Ref 6)..... ☐
7. Purge process gas system with N₂ (Ref 1, sec 3.3, p 3-5; Ref 4, switch-on 2, ②, LN, RN, 17 & 24, 14 & 24, 13/24)..... ☐
8. Leak test process gas system (Ref 1, sec 4.4, p 4-5, 4-6)..... ☐
9. Turn on process gas cylinders. Set pressure regulators at 30-100 psi (Ref 1, sec 2.7, p 2-11)..... ☐

CAUTION: SiH_4 is flammable in contact with air or O_2 .
 PH_3 , AsH_3 and B_2H_6 are toxic.
 PH_3 and B_2H_6 are flammable in contact with air or O_2 .
 NH_3 is an irritant, can be flammable with air or O_2 , and reacts with chloride gasses (HCl , SiCl_4).
 N_2O is toxic.
 HCl is an irritant and reacts with NH_3 . Ref 1, sec 2.7, p 2-11, 2-12, 2-13, 2-14.

9. Turn on process gas cylinders . Set pressure regulators at 30-100 psi (Ref 1, sec 2.7,p 2-11)..... ☐
10. Check operations of process gas system by manual operations of graphic panel switches. (Ref 1, sec 3.3A, B, C, E, H, p 3-5, 3-6, 3-7, 3-8, sec 3.4A, B, C, p 3-8, 3-9; Ref 4, all graphic panel witches, all mass flow controllers, rotometers: Purge N_2 , Purge H_2)..... ☐
11. Check back pressure gauges to verify correct operations of vent exhaust sysytem (Ref 1, sec 2.8, p 2-14; Ref 10 right and left gauges)..... ☐
12. Load SiCl_4 source into bubbler if needed. (Ref 1, sec 3.3D, p 3-6)..... ☐
13. Check operation of HEPA filter. Check cleanliness of loading area (Ref 1, sec 1.8, p 1-5, sec 4.18, p 4-13)..... ☐
14. Check operations of wafer track and loading/unloading wafers on susceptor.
15. Check operations of RF chamber doors (Ref 1, sec 3.3G, p 3-7)..... ☐
16. Check operations of reactor tube loading doors (Ref 1, sec 1.8, p 1-6, sec 3.5C & G, p 3-9, 3-10; Ref 12 Tube Doors)..... ☐
17. Check operations of loading/unloading susceptor and holder into reactor tube..... ☐
18. Check that required maintenance has been done (Ref 1, sec 4.1 through 4.18, p 4-1 through 4-13)..... ☐

19. Start-up the closed loop water recirculator on RF generator. Check DI water level and purity (Ref 7, sec 4.2, p 18 & 19; Ref 1, sec 3.2, p 2-3, 2-4; Ref 8, pump switch)..... ☐
20. Check that RF control indicates RF Off (Ref 5 switch RF Off; Ref 1, sec 3.3E, p 3-7)..... ☐
21. Check settings on RF generator (Ref 7, sec 4.3, p 19, sec 4.4, p 19, 20; Ref 8, Filament Switch; Ref 9, meters, switch, indicator lights)..... ☐
22. Start-up RF generator, check for proper functioning (Ref 9, Start-up switch; Ref 1, sec 3.3F & G, p 3-7)..... ☐

CAUTION: Personnel using heart pacemakers can be exposed to harmful radiation in the vicinity of RF equipment. The RF generator enclosure has a high-voltage exposure hazard and the load coil or load coil leads can cause RF burns if touched (Ref 7, sec 3, p 17 & 18).

23. Check for proper operation of RF reactor automatic temperature controller (Ref 1, sec 1.6, p 1-4, 1-5; Ref 5 automatic temperature controller)..... ☐
24. Check and calibrate susceptor temperature (Ref 1, 3.7, p 3-14, 3-15)..... ☐

Initializing System

1. Establish initial conditions for gas control system.
Select Manual/Automatic operations (Ref 1, sec 3.3,
p 3-5,3-6,3-7,3-8, sec 3.4, p 3-8; Ref 4, Graphic
panel switches and mass flow controllers)..... ☐
2. Establish initial conditions for electronic system.
reactor control unit, select Local/Remote operations.
automatic temperature controller and real time pro-
grammer (Ref 1, sec 3.6, p 3-10. sec 3.8C, p 3-17,
3-18, sec 3.4C, p 3-9,sec 3.7A & B, p 3-12, 3-13;
Ref 5, reactor control unit, automatic temperature
controller, real time programmer)..... ☐
3. Establish initial condition of RF generator. (Ref 1,
sec 2.3, p 2-3, 2-4, 2-5; Ref 7, sec 4.3, p 19 & 20;
Ref 8, Filament switch; Ref 9, meters, switches and
indicator lights correct)... .. ☐
4. Start up wafer track and load station..... ☐
5. Susceptors and holders are stored in N₂ purged reactor tube
(Ref 1, sec 3.5, p 3-9)..... ☐
6. Reactor control unit SAFE light is on and automatic temp-
erature Controller RF switch is off (Ref 1, sec 3.2C,
p 3-3,3-5, sec 3.3E, p 3-7)..... ☐

II. OPERATING/PROCESSING STEPS

Operations of the system are done in either the automatic or manual mode.

1. Check to make sure that Preconditioning/Calibration and Initializing conditions have been met (Ref 1, sec 3.1, 3.2, 3.3, 3.4, p 3-1 to 3-9)..... ☐
2. Bring wafers on air track up to loading station..... ☐
3. Open door of one reactor tube (Ref 1, sec 3.5C, p 3-9; Ref 10, Door switch)..... ☐
4. Unload susceptor from this reactor tube (Ref 1, sec 3.5, p 3-9, 3-10; Ref 11, Unload switch and indicators)..... ☐

CAUTION: Never use metal rod to retrieve or place susceptor and susceptor boat. Severe shock can result from RF coupling.

5. Load wafers on susceptor..... ☐
6. Load susceptor into reactor tube and close door (Ref 1, sec 3.5, p 3-10; Ref 11, Load switch and indicators; Ref 10, Door switch)..... ☐
7. Repeat Steps 3, 4, 5, & 6 above for the other reactor tube..... ☐
8. Open gas pressure regulator panel valve to desired reactant gas source. Graphic panel switch set to vent (Ref 3, dopant gas valves)..... ☐

CAUTION: Never allow NH_3 to flow in any part of the system when chlorides (HCl , SiCl_4) are present. Purge before NH_3 use with Exhaust Purge and after NH_3 use with NH_3 exhaust purge (Ref 3, dopant gas valves, Exhaust Purge valve, NH_3 Exhaust Purge valve)

9. Activate PRE N₂ and PRE H₂ Purge (Ref 1, sec 3.6, p 3-10, 3-11; Ref 5, PRE N₂ and PRE H₂ Switches)..... ☐
10. When STDBY Light comes on, then select tube for run. Ready light will come on (Ref 1, sec 3.6, p 3-11; Ref 5, Standby light, Reactor Tube Select switch and Ready light)..... ☐
11. Automatic Mode, Graphic Panel switch in AUTO position. Activate AUTO OPER switch. (Ref 1, sec 3.8A, p 3-16; Ref 4, Manual/Auto switch; Ref 1, sec 3.8D, p 3-18; Ref 5, Auto Oper switch)..... ☐

CAUTION: Check to make sure that flowmeter rates are essentially the same to reactor as to vent. Reset Exhaust Purge Control valve if needed (Ref 1, sec 4.6, p 4-7)

12. Check susceptor temperature as needed (Ref 1, sec 3.7, p 3-14, 3-15)..... ☐
13. Manual mode, Graphic Panel switch in MANUAL position. (Ref 1, sec 3.7, p 3-12; Ref 4, Manual/Auto Switch)..... ☐
14. Operate graphic panel switches to select gas flows into reactor tube. (Ref 1, sec 3.7, p 3-12; Ref 4, gas solenoid switches)..... ☐

CAUTION: Check to make sure that flowmeter rates are essentially the same to reactor as to vent. Reset Exhaust Purge valve if needed. (Ref 1, sec 4.6, p 4-7).

CAUTION: Never allow NH_3 to flow in any part of the system when chlorides (HCl , SiCl_4) are present. Purge before NH_3 use with Exhaust Purge and after NH_3 use with NH_3 Exhaust Purge (Ref 3, Dopant Gas valve and NH_3 Exhaust Purge valve).

15. Check susceptor temperature as needed (Ref 1, sec 3.7, p 3-14, 3-15). ☐
16. When run is completed, turn off RF source to RF coil (Ref 1, sec 3.7D, p 3-13; Ref 5, RF Off Switch)..... ☐
17. Post purge reactor tube with H_2 and then N_2 (Ref 1, sec 3.7E, p 3-13; Ref 5, POST H_2 and POST N_2 switches)..... ☐
18. Make run in the other tube if needed. Automatic mode repeat steps 11 and 12. Manual mode repeat steps 13 through 17..... ☐
19. When SAFE light is on the reactor doors are opened, the susceptors are unloaded, the wafers are unloaded from the susceptors and the wafers removed by the air track (Ref 1, sec 3.9, p 3-19; Ref 5, Safe Light; Ref 10, Door switch, Ref 11, Unload switch and indicators)..... ☐

CAUTION: Never use metal rod to retrieve susceptor and susceptor boat. Severe shock can result from RF coupling.

III.

NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic or manual mode.
All wafers are removed from the reactor tubes.

Short-Term Shut-Down (1 - 10 days)

1. Establish final conditions. (Ref 1, sec 3.9, p 3-19)..... ☐
2. Close all valves on all process gas cylinders (Ref 1, sec 2.7, p 2-11, 2-12, 2-13, 2-14)..... ☐
3. Close valve on H₂ at incoming gas control system panel (Ref 1, sec 3.2D, p 3-5; Ref 3, Main H₂ Valve)..... ☐
4. Close all process solenoid valves on graphic panel (Ref 1, sec 3.3, p 3-5; Ref 4, graphic panel switches)..... ☐

CAUTION: Maintain N₂ purge flow in reactor tube (Ref 1, sec 3.2B & C, p 3-1, 3-3, 3-5)

5. Close both reactor load doors (Ref 12, load doors)..... ☐
6. Turn off H₂ burn-off system..... ☐
7. Leave exhaust vent system on. Turn off exhaust scrubber (Ref 1, sec 2.8, p 2-14, 2-15)..... ☐
8. Shut down wafer track and loading system..... ☐
9. Leave main AC power on (Ref 1, sec 3.2, p 3-1; Ref 2, Switches 1, 2, 3, 4, & 5)..... ☐
10. Shut down RF generator (Ref 7, sec 4.6, p 25; Ref 9, RF Power switch; Ref 8, Filament, Pump and Generator switch)..... ☐
11. Shut down raw water supply to RF generator heat exchanger (Ref 1, sec 2.3, p 2-3)..... ☐

Long Term Shut-Down (> 10 Days)

1. Perform steps 1, 2, 3, 5, 8, 9, 10 & 11 as indicated above for Short-Term Shut-Down..... ☐
2. Relieve pressure in process gas system (Ref 1, sec 3.3, p 3-5, 3-6; Ref 4 open solenoid switches)..... ☐
3. Purge process gas system with N₂ to vent (Ref 1, sec 3.3, p 3-5, 3-6; Ref 4, solenoid switches)..... ☐
4. Close process gas solenoid switches (Ref 4, solenoid switches)..... ☐
5. Turn off H₂ burn-off system..... ☐
6. Turn off exhaust gas scrubber. Turn off exhaust vent system. (Ref 1, sec 2.8, p 2-14, 2-15)..... ☐
7. Close valve on N₂ at incoming gas control system panel (Ref 1, sec 3.2B, p 3-1; Ref 2, Main N₂)..... ☐
8. Turn off main AC power (Ref 1, sec 3.2, p 3-1; Ref 2, switches 1, 2, 3, 4, & 5)..... ☐

The need for maintenance is determined by inspection after normal shutdown.

1. Check and clean reactor tube and door as needed (Ref 1, sec 4.3, p 4-2, 4-3, 4-4, 4-5, sec 4.7, p 4-7)..... ☐

CAUTION: Do not touch quartz tube with bare hands. Use gloves. Eye, face and hand protection are required when cleaning tube with HF/HNO₃ acid mixture (Ref 1, sec 4.3, p 4-3).

2. Check and clean susceptor as needed. (Ref 1, sec 3.1, p 3-1, sec 4.2, p 4-1, 4-2)..... ☐

CAUTION: Do not touch susceptor with bare hands. Use gloves.

3. Leak test reactor tube. (Ref 1, sec 4.4, p 4-5)..... ☐
4. Check and clean gas rotometers as necessary. (Ref 1, sec 4.11, p 4-11)..... ☐
5. Check, clean and leak test process gas system (Ref 1, sec 3.3A, B, C, D, p 3-5, 3-6; Ref 4, solenoid valve switches; Ref 1, sec 4.4, p 4-5, 4-6, sec 4.5, p 4-6, 4-7, sec 4.8, p 4-8, sec 4.9, p.4-8, sec 4.10, p 4-8, sec 4.16, p 4-11)..... ☐
6. Replace in-line gas filters as needed (Ref 1, sec 4.14, p 4-10)..... ☐
7. Check exhaust vent system (Ref 1, sec 4.5, p 4-6, sec 4.6, p 4-7)..... ☐
8. Clean and lubricate mechanical equipment (Ref 1, sec 4.13, p 4-11)..... ☐
9. Clean and aim Pyrometer (Ref 1, sec 4.15, p 4-10)..... ☐
10. Profile RF coil (Ref 1, sec 4.19, p 4-13)..... ☐

IV.

EMERGENCY SHUT-DOWN STEPS

Chemical Problem Shut-Down

This can be caused by reactive gas explosion or fire, large gas system leak(s), gas flow from reactor tube (door leak, crack or rupture) or exhaust vent system and scrubber failure.

1. Activate fire extinguisher system if needed..... ☐
2. If run can be safely and conveniently terminated, then override to start POST N₂ Purge (Ref 1, sec 3.11, p 3-20; Ref 5, POST N₂ Switches)..... ☐
3. Close valves on process gas cylinders (Ref 1, sec 2.7, p 2-11, 2-12, 2-13, 2-14)..... ☐

CAUTION: If exhaust system is not working and process gas sources cannot be safely turned off, then enter room only with self-contained air breathing equipment to extinguish fire or close valves. (Ref 13)

4. Close valve on H₂ gas source at incoming gas control system Panel (Ref 1, sec 3.2D, p 3-5; Ref 3, Main H₂ Valve)..... ☐
5. Switch off RF Generator (Ref 7, sec 4.6, p 25; Ref 9, RF Power switch; Ref 8, Filament, Pump and Generator switch)..... ☐

CAUTION: The RF Generator enclosure has high-voltage exposure hazard. Proper grounding is necessary if enclosure is opened.

6. Switch off main AC power (Ref 1, sec 3.2, p 3-1; Ref 2, switches 1, 2, 3, 4, & 5)..... ☐

7. Close valve on N₂ purge gas source at incoming gas control system panel (Ref 1, sec 3.2B, p 3-1, Ref 3, Main N₂ valve)..... ☐
8. Force ventilate the room. Test for toxic or flammable gas residue..... ☐
9. Shut down exhaust gas scrubber, turn off exhaust vent system (Ref 1, sec 2.8, p 2-14, 2-15)..... ☐

Electrical or Mechanical Problem Shut-Down

This can be caused by power outages, voltage excursions, shorts, damage to wire and insulation, damage or defects in RF system, defects in electrical equipment (motors, solenoids, interlock circuits), malfunctions of mechanical equipment, handling equipment, instruments and meters, solenoid valves and pressure regulators.

1. If run can be safely and conveniently terminated, then override to start POST H₂ purge (Ref 1, sec 3.11, p 3-20; Ref 5, POST N₂ switches)..... ☐
2. Switch off RF generator (Ref 7, sec 4.6, p 25; Ref 9, RF power switch; Ref 8, Filament, Pump and Generator switch)..... ☐

CAUTION: The RF generator enclosure has high-voltage exposure hazard. Proper grounding is necessary if enclosure is opened.

3. Close valves on process gas cylinders (Ref 1, sec 2.7, p 2-11, 2-12, 2-13 & 2-14)..... ☐

CAUTION: If exhaust system is not working and process gas cylinders cannot be safely turned off, then enter room only with self-contained air breathing equipment to close valves and shut down equipment. (Ref 13)

4. In a power failure, the normally open N₂ purge will continue to function (Ref 1, sec 3.2C, p 3-3, 3-5)..... ☐
5. Close valve on H₂ gas source at incoming gas control system panel (Ref 1, sec 3.2D, p 3-5; Ref 3, Main H₂ valve)..... ☐

6. Switch off main AC power (Ref 1, sec 3.2, p 3-1;
Ref 2, switches 1, 2, 3, 4, & 5)..... ☐
7. Close valve on N₂ purge gas source at incoming
gas control system panel (Ref 1, sec 3.2B, p 3-1;
Ref 3, Main N₂ valve)..... ☐
8. Shut-down exhaust gas scrubber. Turn off exhaust vent
system (Ref 1, sec 2.8, p 2-14, 2-15)..... ☐

V.

EMERGENCY SHUT-DOWN

CLEAN-UP, INSPECTION, AND REPAIR STEPS

Resulting from Chemical Problems

1. Make sure AC power is turned off (Ref 1, sec 3.2, p 3-1; Ref 2 switch 1, 2, 3, 4, & 5)..... ☐
2. Vacuum up any dry extinguisher powder on cabinets, walls and floors..... ☐
3. Vacuum and wipe with alcohol the internal cabinet areas (Ref 1, sec 4.12, p 4-11)..... ☐
4. Wipe external cabinets, gages, meters with detergent and water (Ref 12, module cabinet)..... ☐
5. Wipe wafer loading area and wafer track with alcohol (Ref 1, sec 4.12. p 4-11; Ref 12, wafer loading area)..... ☐
6. Re-vacuum and wet-mop floors..... ☐
7. Check for fouling of HEPA filter. Replace as needed (Ref 1, sec 1.8, p 1-5, sec 4.18, p 4-13)..... ☐
8. Check for proper operations of hazardous gas monitor (Ref 6)..... ☐

Resulting From Electrical or Mechanical Problems as Well
as Chemical Problems

1. Make sure AC power is turned off (Ref 1, sec 3.2,
p 3-1; Ref 2 switch 1, 2, 3, 4, & 5)..... ☐
2. Inspect/test and repair electrical wiring
and insulation damage..... ☐

CAUTION: Make sure all equipment is properly
grounded. Make sure RF generator
high-voltage is discharged before
inspection or repairs (Ref 2, sec 3,
p 16).

3. Selectively switch on all equipment AC power
for testing (Ref 1, sec 3.2, p 3-1; Ref 2,
switch 1, 2, 3, 4, & 5: Ref 7, sec 4.5, p
20 & 21; Ref 9 Start-Up button)..... ☐
4. Clean, inspect and repair vent exhaust and
scrubber system (Ref 1, sec 2.8, p 2-14, 2-15)..... ☐
5. Clean and check operations of N₂ and H₂ Gas
regulators, solenoid valves, flowmeters and
mass flowmeters. Set pressure regulators.
(Ref 1, sec 3.2B & D, p 3-1, 3-5)..... ☐
6. Clean and check operations of process gas regulators,
solenoid valves and switches, flowmeters, mass flow
controllers and pressure relief valves. Purge all
lines with N₂ (Ref 1, sec 4.8, 4.9, 4.10, p 4-8,
4-9, sec 4.16, p 4-11)..... ☐
7. Pressure/leak test process gas system (Ref 1,
sec 4.4, p 4-5, 4-6)..... ☐
8. Clean and check reactor tube exhaust line
and exhaust purge lines (Ref 1, sec 4.5,
p 4-6, 4-7, sec 4.6, p 4-7)..... ☐

9. Clean and inspect reactor tube and door.
Replace door gasket as needed. (Ref 1,
sec 4.3. p 4-2, 4-3, 4-4, 4-5)..... ☐
10. Clean, inspect and adjust RF coils.
Inspect and repair RF generator leads.
(Ref 1, sec 4.19, p 4-13)..... ☐
11. Clean, inspect and check operations of
RF Chamber forced air circulation system.
(Ref 1, sec 1.7, p 1-15, sec 4.18, p 4-13)..... ☐
12. Clean, inspect and test hazardous gas
monitor system (Ref 6)..... ☐
13. Clean, inspect and test operations of air
track, wafer loading and furnace loading
systems through a load/unload cycle..... ☐
14. When system checks are complete, then go
to normal shut-down steps or to precondition/
calibration steps as needed..... ☐

APPENDIX

References

1. Instruction Manual, Unipak Reactor System, August, 1974, Unicorp Inc.
2. Equipment Photo, Power Input and Fuse Panel.
3. Equipment Photo, Incoming Gas Pressure Regulator Panel.
4. Equipment Photo, Graphic Control Panel and Mass Flow Controllers.
5. Equipment Photo, Reactor Control Unit, Automatic Temperature Controller and Real Time Programmer.
6. Equipment Photo, Hazardous Gas Detector and Monitor.
7. Instruction Manual for Induction Heating Generator T-60-3-KC-TL, Manual No. 13190062, Lepel High Frequency Labs, Inc.
8. Equipment Photo, RF System Generator Pump and Filament Switch.
9. Equipment Photo, RF System, Meters, Switch and Indicators.
10. Equipment Photo, Reactor Control Station.
11. Equipment Photo, Reactor Loader Control Panel.
12. Equipment Photo, Epitaxial Module.
13. Instruction Manual, Survivair 30-Minute Unit, September, 1977, Survuvair Inc.

OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

1-PRECONDITION/CALIBRATION STEPS

Utilities and Gases

1. Turn-on N₂. Check pressure regulator setting. (Ref. 1; Ref. 2, Sec. VI B4, P.32). ☐
2. Turn-on cooling water. Check for proper flow rate through each loop. (Ref. 1; Ref. 2, Sec. IV, P.7, Sec. VI B3, P. 32). ☐
3. Turn-on machine AC electric power (Ref. 2, Sec. VI B1, P. 32). ☐

CAUTION:

Make sure all equipment is properly grounded. (Ref. 8, P. 82-93).

4. Turn-on compressed air. Check pressure regulator setting (Ref. 1; Ref. 2, Sec. VI, B 5, P. 32). ☐

Equipment Check

1. Check operations of vent gas exhaust system. ☐
2. Check roughing pump oil level and operation at 3 stations. ☐
3. Check oil level in diffusion pumps at 3 stations. ☐
4. Check operation of LN₂ system and control panel. (Ref. 1, Sec. B 4, P. 1; Ref. 2, Sec. VI B 6, P. 32; Ref. 3, Ref. 8). ☐

CAUTION:

Eye, face, and hand protection needed when manually handling or exposed to LN₂ (Ref. 8, P. 185-187).

5. Purge feed gas handling system. Check feed gas bottle connections and pressure regulator. (Ref. 2, Sec. V D 1). ☐
6. Check operations of wafer track, buffer tees, wafer-matic and carousel. ☐

Initializing System

1. Start-up at stations 1, 2, and 3 roughing pumps. Stabilize systems under low vacuum with isolation gate valves open. (Ref 1, A 1, P 1). ☐
2. Start-up diffusion pump station no. 1. (Accelerator Column) (Ref. 1, Sec. B 1, 2 & 3, D 7 & 8, P. 1; Ref. 4). ☐
3. Turn-on vacuum gauge (Ref. 1, Sec. D 9, P. 1; Ref. 4). ☐
4. Start-up diffusion pump station No. 2 (Scanner Tee) (Ref. 1, Sec. D & G, P. 1; Ref. 2, Sec. V M P. 25). ☐
5. Start-up diffusion pump station No. 3 (Target Chamber) (Ref. 1, Sec. C 5 & 6, E 10-16, P. 1). ☐

CAUTION:

Never shut-down diffusion pumps while system is under vacuum and isolation valve is open. Close valve and vent with N² to atmospheric before shut-down. High foreline pressure will cause automatic shut-down of diffusion pump.

6. Switch LN² controller to auto position for 3 locations (Ref. 1, Sec. B 4, P. 1; Ref. 3). ☐

CAUTION: Lock terminal door and remove key.

7. Turn-on dopant gas sources in the high voltage terminal. (Ref. 1, Sec. F, P. 1; Ref. 2, Sec. V D, P. 12). ☐
8. Turn-on wafer handling system. (Ref. 1, Sec. H.). ☐
9. Turn-on AC power at current integrator panel. (Ref. 1, Sec. I-23, P. 2; Ref. 4). ☐
10. Turn-on magnet control power supply. (Ref. 1, Sec. I-24, P. 2; Re. 5). ☐
11. Turn-on ion source control with key. Turn-on terminal power. (Ref. 1, Sec. I-25 & 26, P. 2; Ref. 5). ☐

CAUTION:

Personnel who normally work in the area of the ion source should wear a radiation badge when this equipment is in operation. (Ref. 6).

12. Turn-on high voltage power supply (Ref. 1, Sec. I-26, P. 2; Ref. 5). ☐
13. Turn-on and fine tune the ion beam (Ref. 1, Sec. I-28 & 29, P. 2; Ref. 5). ☐
14. Turn-on deflector power supply adjust HV output. (Ref. 5; Ref. 6). ☐
15. Turn-on quadripole power supply. Adjust 1 and 2 settings (Ref. 4). ☐
16. Turn-on beam scanner and hybrid tracking control. (Ref. 3, Ref. 6). ☐
17. If no interlocks have been located as indicated by absence of alarm, then system is ready to run. (Ref. 6). ☐
18. Set buffer tee's position. (Ref. 1, Sec. J-30, P. 2). ☐

2-OPERATING STEPS

OPERATION OF THE SYSTEM IS DONE IN THE COMPLETELY AUTOMATIC MODE.

1. Check to make sure initializing conditions have been met. ☐
2. Load wafers (Ref. 1, Sec. J-31, P. 2; Ref. 6). ☐
3. Start run (Ref. 1, Sec. J-32, P. 2; Ref. 6). ☐
4. Run can continue and additional runs made as long as interlock conditions are met. (Ref. 2, Sec. IV). ☐

3-NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic mode. All wafers are removed from the system. ☐

1. Switch-off ion beam and high voltage power supply. (Ref. 1, Sec. K142, P. 2; Ref. 5). ☐

2. Switch-off terminal power and switch-off ion source control with key. Remove key. (Ref. 1, Sec. K 3 & 4, P. 2; Ref. 5). ☐
3. Switch-off magnet control power supply. (Ref. 1, Sec. K 5, P. 2; Ref. 5). ☐
4. Switch-off beam scanner and hybrid tracking control. (Ref. 3; Ref. 6). ☐
5. Switch-off quadripole power supply (Ref. 4). ☐
6. Switch-off deflector power supply. (Ref. 5; Ref. 6). ☐
7. Switch-off AC power at current integrator panel. (Ref. 1, Sec. K6, P. 2; Ref. 4). ☐
8. Turn-off dopant gas sources in the high voltage terminal. (Ref. 1, K 8, P. 2; Ref. 2, Sec. V D, P. 12). ☐
9. Close isolation gate valves on diffusion pumps at 3 locations. (Ref. 1, Sec. L9 & M13, P. 2). ☐
10. Switch-off diffusion pumps at 3 locations. (Ref. 1, Sec. L10 & M14, P. 2). ☐
11. Switch-off vacuum gauge. (Ref. 1, Sec. K7, P. 2; Ref. 4). ☐
12. Switch-off LN₂ controller. (Ref. 1, Sec. M16, P. 2; Ref. 3). ☐

System is now secured in normal pre-run condition. This condition can be maintained for several hours and additional runs made by proceeding through the initializing system steps 2 through 18. If shut-down is for a day or more, then the following additional steps are needed.

13. Open isolation gate valves at 3 locations. ☐
14. Switch-off roughing pumps at 3 locations. ☐
15. Vent purge total vacuum system with N₂ up to atmospheric pressure. ☐
16. Purge dopant gas system with N₂ (Ref. 1, Sec. K8, P. 2; Ref. 2, Sec. VD, P. 12). ☐

17. Turn-off cooling water in diffusion pump loops. ☐
18. Turn-off buffer tees. ☐
19. Turn-off wafer track. ☐
20. Turn-off compressed air. (Ref. 2, Sec. B 5, p. 32). ☐
21. Turn-off main AC power. (Ref. 2, Sec. VI B 1, P. 32). ☐
22. Turn-off N₂ source. (Ref. 2, Sec. B 4, P. 32). ☐
23. Do routine maintenance and preventative maintenance after normal shut-down. ☐

4-EMERGENCY SHUT-DOWN STEPS

Electrical or Mechanical Problem Shut-Down

This can be caused by power outages, shorts, damage to electrical wiring, and defects or malfunctions in electrical equipment and instrumentation systems. Violation of fail-safe or interlock systems will result in shut-down. (Ref. 2, Sec. IV, P 7 & 8). Any of these conditions will probably result in an aborted run.

1. Switch-off ion source control with key. (Ref. 1, Sec. N1, P. 2; Ref. 5). ☐
2. Switch-off AC power at current integrator panel. (Ref. 1, Sec. N2, P. 2; Ref. 4). ☐
3. Switch-off magnet control power supply. (Ref. 1, Sec. M3, P. 2; Ref. 5). ☐

CAUTION: Make sure that equipment is properly grounded. Check for potential electrical shock. (Ref. 8, P. 82-93.)

4. Switch-off beam scanner and hybrid tracking control. (Ref. 3; Ref. 6). ☐
5. Switch-off quadrupole power supply. (Ref. 4). ☐
6. Switch-off deflector power supply (Ref. 5; Ref. 6). ☐

7. Switch-off vacuum instrumentation. (Ref. 1, Sec. N4, M2, P2; Ref. 4). ☐
8. Switch-off diffusion pumps at 3 locations. (Ref. 1, Sec. M1, P.2). ☐
9. In event of power failure, all gate valves will close. Then vent high vacuum system with N₂ up to atmospheric pressure. ☐
10. Switch-off LN₂ controllers at 3 locations. (Ref. 1, Sec. M3, P. 2; Ref. 3; Ref. 8, P. 185-187). ☐
11. Turn-off dopant gas sources in the high voltage terminal. (Ref. 1, Sec. 01, P. 2; Ref. 2, Sec. V D, P. 12). ☐
12. Turn-off wafer track and buffer tee loading system. (Ref. 1, Sec. N5, P. 2). ☐
13. Determine cause of problem and inventory extent of damage. ☐

This level of shut-down is satisfactory for trouble-shooting and maintenance on most electrical or mechanical problems. If the problem is more severe, then the additional steps required for chemical or fire shut-down should be done.

Chemical or Fire Problem Shut-Down

This can be caused by small electrical fires, venting of dopants, gasses or major fires in adjacent areas.

1. Activate fire extinguisher system if needed. ☐
2. Turn-off or isolate any leaking dopant gas bottles. (Ref. 1, Sec. 01, P. 2). ☐
3. Evacuate room, return only if toxicity and flamability sources have been controlled. ☐
4. In event of fire near the air header lines the fusible safety caps will close down the dopant gas flow by bleeding the air header. (Ref. 7). ☐
5. Go through emergency shut-down steps listed above in steps 1 through 11. ☐
6. Switch-off roughing pumps at 3 locations. ☐

7. Vent purge total vacuum system with N₂ up to atmospheric pressure. Vacuum gate valves should be open. ☐
8. Turn-off compressed air. (Ref. 2, Sec. VI, B5, P. 32). ☐
9. Switch-off main AC electric power. (Ref. 2, Sec. VI B1, P. 32). . . ☐
10. Turn-off cooling water. (Ref. 2, Sec. VI, B3, P. 32). ☐
11. Turn-off N₂. (Ref. 2, Sec. VI B4, P. 32). ☐
12. Determine cause of problem and inventory extent of damage. ☐

5-EMERGENCY SHUT-DOWN
CLEAN-UP, INSPECTION AND REPAIR STEPS

1. Make sure main electrical power is switched-off. (Ref. 2, Sec. VI, B1, P. 32.). ☐
2. Clean-up any fire extinguisher or fire damage. ☐
3. Inspect/test and repair electrical wire and insulation damage. . . . ☐

CAUTION: Make sure that all equipment is properly grounded. Make sure that there are no electrical shorts. (Ref. 8, P. 79-93).

4. Switch-on main AC electric power then selectively switch-on all electric powered equipment for operational testing. ☐
5. Test mechanical equipment and make repairs as necessary. ☐
6. Selectively test all vacuum system components, instruments, controllers and interlocks. Perform leak test on vacuum system. . . ☐
7. Test and repair dopant gas system as needed. ☐
8. Test and repair vent gas exhaust system as needed. ☐
9. Test and repair high voltage terminal and ion source equipment, instruments and controllers as needed. ☐
10. Check operations of wafer track and wafer loading system. ☐

11. Check filters and operations of ultra-clean work/loading station. . ☐
12. When system checks are successfully completed then either go to normal shut-down stable condition or to the precondition/calibration steps for additional runs. ☐

6-APPENDIX

References

1. Ion Implanter System Routine.
2. Technical Data Manual on Model MP Implanter, Accelerators Inc., 1973.
3. Photo of instrumentation and control panel for hybrid tracking control, beam scanner, LN₂ controller and deflector power supply.
4. Photo of instrumentation and control panel for pump station No. 1, current integrator and quadripole controls.
5. Photo of instrumentation and control panel for H.V. power supply, magnet control and ion source control.
6. Ion implanter radiation protection guide, MSFC, 11-29-78.
7. Fusible safety fittings, eutect melting points of 160, 255 and 281°F. Franklin Valve and Fitting Co.
8. Safety and Environmental Health Standards, MM 1700.4B, MSFC, Oct. 15, 1974.

OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

SYSTEM ROUTINE
REFERENCE 1

A. SYSTEM PRECONDITION

1. System under low vacuum
2. Cooling water on.
3. G_{N2} on.

NOTE: If a malfunction occurs at any point isolate the problem, correct problem and continue.

B. OPERATIONAL PROCEDURE

Sequence

Pump Station no. 1 Panel

1. Check foreline pressure station no. 1 (5 microns or less reading on meter).
2. Turn Hi-vac valve switch (pump sta. no. 1) to the manual closed position.
3. Turn (diffusion) pump on.
4. Turn L_{N2} (station no. 1 and 2) to the auto position (L_{N2} control panel to the left of pump sta. panel).

C. CHAMBER STATION PANEL

5. Turn Torr Gauge (power) on (located directly under the scan monitor panel).
6. Turn (diffusion) pump on.

D. PUMP STATION NO. 1

7. Check rough pressure station no. 1 (monitor meter 5 micron or less, Thermocouple Selector switch in roughing position).
8. Turn Hi-vac valve switch to the unprotected open position.

When the L_{N2} traps are full and the system chilled down (approx. 30 min.) continue.

9. Turn NRC 855 (Hi-vac) gauge power on (locate top panel of the control console).

E. CHAMBER STATION

10. Turn foreline valve switch to closed position.
11. Turn roughing valve switch to open position.
12. Monitor meter, when pressure is less than 50 microns close roughing valve and open foreline valve.
13. Turn the Hi-vac switch to unprotected open position.
14. Turn the Torr gauge filament (power) on (above).
15. Turn the terminal L_{N2} Switch to Auto Position (sta. no. 1 on L_{N2} Control Panel).
16. Turn the Hi-vac switch to the Protected Open Position.

OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

SYSTEM ROUTINE
REFERENCE 1

F. TERMINAL ROOM

17. Turn Source Gas on. (Allow to stabilize monitor NRC 855 gauge) (Hi-voltage).
18. Lock Terminal door and remove key.

G. PUMP STATION NO. 1

19. Turn Hi-vac valve switch to Protected open position.
20. Turn isolation valve switch to Protected open position.

H. WAFER MATIC

21. Turn wafer matic power on (Switch located inside of the function cabinet.)
22. Turn Buffer-Tee's power on (Switches on instruments).

I. CONTROL CONSOLE

23. Turn the Current Intergrater Function Switch to the operate position.
24. Turn the magnet control (power) on.
25. Insert key (in Ion Control Panel) and turn keyed power on.
26. Turn Terminal power on (ion control panel).
27. Turn Hi-voltage power supply on (adjust to desired level).
28. Turn Ion Beam on (ion control panel).
29. Fine tune ion beam, machine ready to operate.

J. WAFER-MATIC

30. Set Buffer-Tee's to the proper operating position (function panel feed/load reset buttons).
31. Load wafers.
32. Press run button.

SHUT DOWN PROCEDURE

K. CONTROL CONSOLE

1. Turn Beam off.
2. Run Hi-voltage control to zero volts, then off.
3. Turn Terminal Power off.
4. Turn console key off and remove key.
5. Turn magnet current to zero, then off.
6. Turn current Intergrater Function Switch to the A.C. OFF Position.
7. Turn the NRC 855 Gauge Power off.
8. Turn source gas off. (In Terminal Room).

OPERATIONS AND SAFETY CHECKLIST
ION IMPLANTER

SYSTEM ROUTINE
REFERENCE 1

L. PUMP STATION NO. 1

9. Turn isolation valve to closed position.
10. Turn (diffusion) Pump off.
11. Turn Hi-vac valve switch to the closed position.

M. CHAMBER STATION

12. Turn Torr Gauge filament off (panel above).
13. Turn Hi-vac valve switch to the closed position
14. Turn (diffusion) Pump off.
15. Turn all LN₂ station off (LN₂ Control Panel).
16. System secured at the normal pre-operation condition.

EMERGENCY SHUT DOWN PROCEDURE

N. AT CONSOLE

1. Turn power off with key (remove key).
2. Turn current integrater (ac power) off.
3. Turn magnet power off.
4. Turn NRC 855 Gauge off.
5. Turn wafer-matic and Buffer's-"T"'s off.

O. AT PUMP AND CHAMBER STATION

1. Turn (diffusion) pumps off.
2. Turn Torr Gauge filament off, then power off.
3. Turn all LN₂ off.

P. AT TERMINAL ROOM

1. Turn source gas off.
2. Make sure the roughing pump at station no. 1 continues to run.

HYBRID TRACKING CONTROL

REF
3

DEFLECTION
VERT SCAN
HORIZ SCAN

MAIN POWER

VERTICAL

Model 100-1
beam scanner

HORIZONTAL



OSCILLOSCOPE

UPPER LOWER



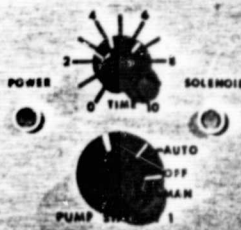
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ON
HV
OFF

OSCILLOSCOPE

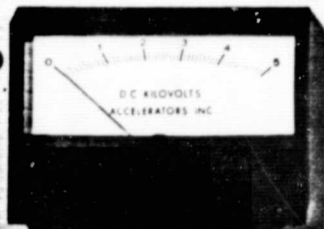
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LN₂ CONTROLLER

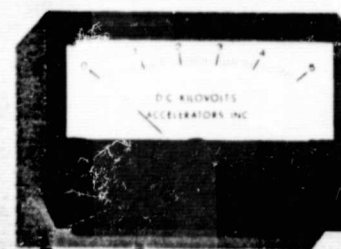


DEFLECTOR POWER SUPPLY

± 5KV.



HV CONTROL
INTERNAL EXTERNAL



QUADRUPOLE P.S.

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Accelerators Inc.

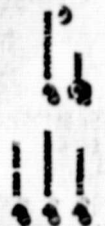
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H.V. POWER SUPPLY
0-100 V 10 mA

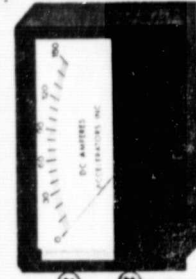
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Accumulator Inc.



MAGNET CONTROL

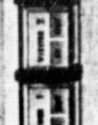
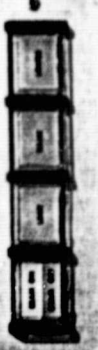
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STOP



ION SOURCE CONTROL

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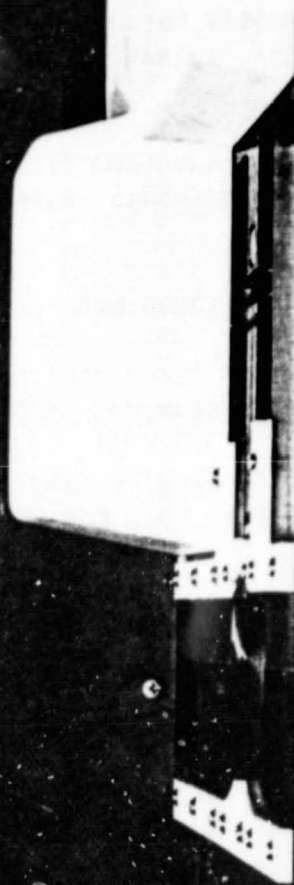
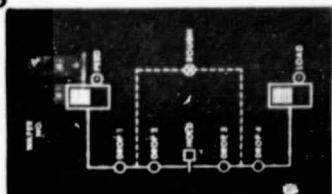
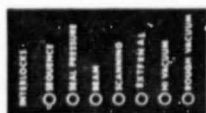


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OPERATIONS AND SAFETY CHECKLIST
ETCHING AND CLEANING

1-PRECONDITIONING/CALIBRATION STEPS

Utilities and Gasses

1. Turn-on N₂ to both etch stations. Set pressure regulator at 40 PSI. (Ref. 1; Ref. 2). ☐
2. Turn-on N₂ to wafer track and load stations. Set pressure regulator at 80 psi (Ref. 1; Ref. 2). ☐
3. Turn-on DI water circulation system. ☐
4. Switch-on main AC electrical power (Ref. 1). ☐

CAUTION: Make sure all equipment is properly grounded. (Ref. 5, P. 82-93).

Equipment Check

1. Switch-on and check proper operations and flow rate of etch facility vent gas system. (Ref. 1; Ref. 3; Ref. 4, Sec. 1, P. 2).. ☐
2. Check operations of vent gas scrubber. Replenish limestone bed as needed. (Ref. 1; Ref. 4, Sec. 9, P. 78). ☐
3. Check and balance operations of total room ventilation and comfort control system. ☐
4. Turn-on and check operations of DI water circulation system. Check operations of polishers and resistivity monitors. (Ref. 1, Ref. . . 3). ☐
5. Check operations of liquid waste effluent system. Check for proper operations of neutralization and pH monitoring system. ☐
6. Check operations of wafer track and load stations. (Ref. 1). . . . ☐
7. Check operations, flow rate and resistivity in six DI water rinse tanks. (Ref. 1; Ref. 3). ☐

8. Check acid etching solutions in seven individual tanks. Replace or replenish each specific solution as needed. (Ref. 1; Ref. 4, Sec. 5, P. 35, Appendix A, P. 80). ☐

CAUTION: Face, hand and body protection required when exposed to or handling acids. Extreme care is required in handling HF acid solutions. Absolute integrity of hand protection is essential. (Ref. 5, P. 11-14, P. 143-144, P. 159-160, P. 165-166, P. 213-216).
In case of acid splash or spill use safety shower or eye wash as needed. Neutralize and absorb spills to eliminate liquid hazard. Ventilate room to eliminate vapor hazard.

9. Check temperature of the BOE acid solution in tank no. 18. Establish at 50°C. All other tanks are at room temperature. (Ref. 1). ☐

10. Check photoresist strip solutions in two tanks. Replace or replenish as needed. (Ref. 1). ☐

CAUTION: Face and hand protection required when exposed to or handling photoresist strip solutions (Ref. 5, P. 1-14, P. 94-106).

11. Check silicon etch solution in tank No. 11. Replace or replenish as needed. (Ref. 1; Ref. 4, Appendix A, P. 81). ☐

CAUTION: Face and hand protection required when exposed to or handling this base solution. (Ref. 5, P. 11-14).

Avoid mixing of acid and base solutions because of possible explosive reaction.

12. Check solvents in tanks No. 9 and No. 10. Replace or replenish as needed. (Ref. 1; Ref. 4, Sec. 5, P. 35). ☐

CAUTION: Face and hand protection suggested when exposed to or handling solvents. (Ref. 5, P. 11-14, P. 94-106, P. 133-134, P. 167-171).

Avoid mixing of strong acids with acetone because of possible explosive reaction.

13. Check operations of tank-to-tank automatic transfer system. (Ref. 1; Ref. 2; Ref. 3). ☐
14. Check operations of instrument and control systems on each module (Ref. 1; Ref. 3). ☐
15. Check operations of wafer washer and drier system. Check control system (Ref. 1; Ref. 3). ☐

Initializing System

1. Load prepared wafers. (Ref. 1). ☐
2. Select etch sequence and time. (Ref. 1; Ref. 2; Ref. 3). ☐
3. Start-up wafer track. (Ref. 1). ☐
4. Start-up load stations. (Ref. 1). ☐

2-OPERATING/PROCESS STEPS

Operations of the system are done in the automatic mode.

1. Check to make sure initializing conditions have been set. ☐
2. Feed wafers into system. ☐
3. Start specific programmed etch sequence (Ref. 1; Ref. 2; Ref. 3). ☐
4. Completed wafers are removed from system. (Ref. 1). ☐
5. Check for depleted etch solutions. (Ref. 1; Ref. 4; Sec. 5; P. 35). ☐
6. Start additional specific etch sequence (Ref. 1; Ref. 2). ☐
7. Make sure DI water resistivity quality specifications and interlocks are maintained. (Ref. 2; Ref. 3). ☐

3-NORMAL SHUT-DOWN STEPS

Operations of the system are completed in the automatic mode. All wafers are removed from system. Shut down can be short term (several hours) or long term (several days).

Short-Term Shut-Down

1. Shut-down wafer track. (Ref. 1). ☐
2. Shut-down loading stations. (Ref. 1). ☐
3. Switch-off instrument and control systems on each etch module and the wafer washer and dryer module. (Ref. 1; Ref. 3). ☐
4. Switch-off DI water monitor (Ref. 3). ☐
5. Shut-down DI water circulation (Ref. 1). ☐
6. Switch-off heat to etch station No. 18. ☐

Long-Term Shut-Down

The following steps are done in addition to the short-term shut-down steps.

1. Drain and dispose of short-life acid and base etching solutions as needed. (Ref. 1; Ref. 4, Sec. 5, P. 35). ☐

CAUTION: Face, hands and body protection required when exposed to or handling acids or bases. Do not mix concentrated acids and bases. (Ref. 5, P. 11-14).

2. Drain and dispose of photoresist strip solutions as needed. (Ref. 1; Ref. 4; Sec. 5, P. 35). ☐

CAUTION: Face and hand protection required when exposed to or handling photoresist strip solutions. (Ref. 5, P. 11-14).

3. Drain and dispose of solvents as needed. (Ref. 1, Ref. 4, Sec. 5, P. 35). ☐

CAUTION: Use care in handling solvents. Do not allow acetone to come in contact with strong acids. (Ref. 5, P. 94-106).

4. Drain DI water rinse tanks. (Ref. 1). ☐
5. Shut-off N₂ to etch stations. (Ref. 1; Ref. 2). ☐

6. Shut-off N₂ to wafer track and load stations. (Ref. 1). ☐
7. Shut-off etch facility vent gas system. (Ref. 1). ☐
8. Switch-off main AC electrical power. (Ref. 1). ☐
9. Normal maintenance and preventative maintenance is done after normal shut-down (Ref. 2). ☐

4-EMERGENCY SHUT-DOWN STEPS

Chemical Problem Shut-Down

This can be caused by accidental mixing of strong acids with acetone or strong base solution. A fire can be caused by ignition of acetone vapor. Fire in an adjacent area can also require shut-down wafers in acid etch solutions should be aborted. Other wafers in process may be salvagable.

1. Activate fire extinguisher system as needed. ☐
2. Shut-down etch facility vent gas system. (Ref. 1; Ref. 4, Sec. 1, P. 2). ☐
3. Switch-off main AC electric power. (Ref. 1; Ref. 5, P. 82-93). . . ☐
4. Turn-off N₂ to etch stations. ☐
5. Turn-off N₂ to wafer track and load station. ☐
6. Drain or dispose of all acid and base etch solutions. (Ref. 4, Sec. 5, P. 35). ☐

CAUTION: Face, hand, and body protection required when exposed to or handling acids, bases and solvents. Do not mix concentrated acid with concentrated bases or acetone.

7. Drain or dispose of all acid and base etch solutions. (Ref. 4, Sec. 5, P. 35). ☐
8. Drain and dispose of solvents as needed. (Ref. 4, Sec. 5, P. 35). . ☐
9. Turn-off DI water circulation System. (Ref. 1). ☐
10. Switch-off individual etch modules. (Ref. 1). ☐
11. Inventory extent of damage. ☐

Electrical/Mechanical Problem Shut-Down

This can be caused by power outages, electrical shorts, and defects or malfunction in mechanical and electrical equipment (motors, solenoids, etc.)

1. Switch-off individual etch modules (Ref. 3) ☐

CAUTION: Check for possible electrical shock hazard (Ref. 5, P. 79-93).

2. Switch-off wafer cleaner and dryer. ☐
3. Shut-down wafer track and loading stations. (Ref. 1) ☐
4. Switch-off heat to etch station No. 18. ☐
5. Do steps 1 through 8 of normal long-term shut-down. ☐
6. Determine cause of problem and inventory extent of damage. ☐

5-EMERGENCY SHUT-DOWN CLEAN-UP, INSPECTION AND REPAIR STEPS

1. Make sure main electrical power is switched-off (Ref. 1) ☐
2. Clean-up any fire extinguisher or splash damage on modules or wafer handling equipment. ☐
3. Inspect/test and repair electrical wire and insulation damage. . . . ☐

CAUTION: Make sure that all equipment is properly grounded. Make sure that there are no electrical shorts. (Ref. 5, P. 79-93).

4. Inspect and test for residual acids, photoresist strip, alkaline etch, oil solvents in tanks. Remove residue and clean tanks as needed. (Ref. 2; Ref. 3) ☐

CAUTION: Face, hand and body protection required because of possible exposure to acids, bases and solvents (Ref. 5, P. 11-14).

5. Inspect, test and repair as needed the vent gas system. ☐
6. Switch-on main AC electrical power and then selectively switch-on all electric powered equipment, controllers and instrumentation for operational testing. (Ref. 2). ☐
7. Test mechanical equipment and make repairs as needed. ☐
8. Check operations of wafer track and loading stations. (Ref. 1). . . ☐
9. When system checks are successfully completed then either go to normal long-term shut-down stable conditions or to the precondition/calibration steps for additional runs. (Ref. 1; Ref. 2). . . ☐

6-APPENDIX

References

1. Wafer Etching and Cleaning Routine, MSFC, 1979.
2. Specifications and Operating Instructions, Model 4000, Automatic Processing System, The Fluorocarbon Co., 1973.
3. Equipment Photo, Etch Station.
4. FED Emission Control Requirements, Integrated Circuit Engineering, June 1978.
5. Safety and Environmental Health Standards, MM 1700. 4B, MSFC, October 15, 1974.



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OPERATIONS AND SAFETY CHECKLIST
PHOTOLITHOGRAPHY

I. PRECONDITION/CALIBRATION STEPS

Utilities and Gasses

1. Turn on N₂ to coater and developer. Set system pressure regulator at 35 PSI and aspirator pressure regulator at 60 PSI. . . ☐
(Ref. 1, Ref. 2, Table 1-1, P. 1-4, Fig. 2-1, P. 2-2.)
2. Turn on N₂ to wafer track and buffer tees. Set pressure regulator at 35 PSI. (Ref. 1, Ref. 3, Sec. 2-9, P. 2-1). ☐
3. Switch on main AC electric power (Ref. 1). ☐

CAUTION: Make sure all equipment is properly grounded. (Ref. 4, P. 82-93).

4. Selectively switch on individually the coater, aligner, developer, bake stations, and buffer tees. (Ref. 1, Ref. 2, Table 1-1, P. 1-4, Fig. 3-1, P. 3-3, Ref. 5, Ref. 6, Ref. 7). ☐
5. Turn on N₂ to soft bake and bake ovens. (Ref. 1, Ref. 6, Sec. 2-11, P. 2-1, Ref. 7, Sec. 2-11, P. 2-1). ☐
6. Turn on vacuum to bake oven. (Ref. 7, Sec. 2-12, P. 2-1). ☐

Equipment Check

1. Switch on and check operations and flow rate of total vent gas system. Ref. 1, Ref. 2, Sec. 2-7, P. 2-6, Ref. 7, Sec. 2-12, P. 2-1). ☐
2. Check operations of wafer track and buffer tees. (Ref. 1, Ref. 3, Sec. 3, P. 3-1 to 3-7). ☐
3. Check operations of coater system. Check photoresist liquid level in reservoir. Replenish as needed. Prime pump, adjust dispensing volume and adjust suckback as needed. (Ref. 1, Ref. 2, Sec. 2-18, P. 2-7, Sec. 2-37, P. 2-15, Sec. 3-17, P. 3-5). ☐

CAUTION: Face and hand protection required when handling or exposed to photoresist fluids. (Ref. 4, P. 94-106 & 137.)

4. Check operations of coater exhaust system. (Ref. 2, Table 1-1, P. 1-4, Sec. 2-8, P. 2-6.) ☐
5. Check operations of soft bake oven. Set controls for required temperature and time. (Ref. 6, Sec. 3-10, P. 3-1, 3-2). ☐
6. Check operations of wafer aligner system in manual and auto modes. Set exposure time. Insert required mask. (Ref. 5, Description of controls and operator instructions.) ☐

CAUTION: Avoid direct eye exposure to UV radiation from Hg ARC lamp. Use eye protection when exposure is possible. (Ref. 4, P. 75-76).

7. Check operations of developer system. Check stoddard solvent and N-butyl acetate liquid level in reservoirs. Replenish as needed. Prime pumps and adjust dispensing volumes as needed. (Ref. 1, Ref. 2, Sec. 2-18, P. 2-7, Sec. 2-37, P. 2-15.) ☐

CAUTION: Face and hand protection needed when handling or exposed to solvents. (Ref. 4, P. 94-100, P. 135).

8. Check operations of developer exhaust system. (Ref. 2, Table 1-1, P. 1-4, Sec. 2-8, P. 2-6). ☐
9. Check operations of bake oven. Set controls for required temperature and time. Check for proper operations of exhaust system. (Ref. 7, Sec. 2-13, P. 2-1 and 2-4, Sec. 3-3 and 3-9, P. 3-1). ☐

Initializing System

1. Load prepared wafers. ☐
2. Start up coater module. Load program into memory as needed. (Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-9, P. 3-4, Sec. 4-26 to 4-38, P. 4-5 to 4-7). ☐
3. Start up soft bake station. (Ref. 6, Sec. 3-11 and 3-12, P. 3-2). . . ☐
4. Start up wafer aligner module. (Ref. 5, Operator Instructions). . . ☐
5. Start up developer module. Load program into memory as needed. (Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-9, P. 3-4, Sec. 4-26 to 4-38, P. 4-5 to 4-7). ☐

6. Start up bake station. (Ref. 7, Sec. 3-9, and 3-10, P. 3-1). . . . ☐
7. Start up buffer tees. (Ref. 3, Sec. 3-5 to 3-28, P. 3-1 to 3-6). . ☐
8. Start up wafer track. (Ref. 1). ☐

2-OPERATIONS/PROCESS STEPS

Operations of the system are normally done in the automatic mode. The individual modules can be operated in the manual mode.

1. Check to make sure initializing steps have been completed. (Ref. 1, Ref. 2, Ref. 3, Ref. 5, Ref. 6, Ref. 7). ☐
2. Check that wafers are properly loaded. (Ref. 1). ☐
3. Automatic Mode. Operate total system in remote/auto mode. (Ref. 1, Ref. 2, Sec. 3-11 and 3-13, P. 3-4 and 3-5, Ref. 3, Sec. 3-6, P. 3-1, Ref. 6, Sec. III, P 3-1 and 3-2, Ref. 5, Operator Instructions, 31, P. 2, Ref. 7, Sec. III, P. 3-1). ☐
4. Manual Mode. Operate individual stations in local/manual mode. (Ref. 1, Ref. 2, Sec. 3-4, 3-13, P. 3-1, 3-2, 3-3, 3-5, Ref. 5, Operator Instructions P. 1 to 3). ☐
5. Completed wafers are removed from the total system into storage or transferred to etch and cleaning system. ☐
6. Run will continue until wafer fees ceases or a station malfunction stops process. (Ref. 1, Ref. 2, Sec. 3-13, P. 3-5, Ref. 2, Sec. 3-8, P. 3-1, Ref. 5, Manual Eject). ☐
7. Change mask in aligner and start another run in either auto or manual mode. (Ref. 1, Ref. 5, Mask Load Instructions). ☐
8. Remove wafers from system. (Ref. 1). ☐

3-NORMAL SHUT DOWN STEPS

Operations of the system are completed in the automatic or manual mode. All wafers are removed from the coater, soft bake oven, aligner, developer and bake oven. Short term storage of wafers in buffer tees is possible.

Short Term Shut Down

1. Shut down wafer track. Turn off N_2 supply. (Ref. 1). ☐
2. Shut down buffer tees. Switch off electric power and turn off N_2 supply. (Ref. 3, Sec. 2-10, P. 2-1, Fig. 3-1, P. 3-2, Sec. 3-23, P. 3-5). ☐
3. Shut down coater module. Switch off system electric power. (Ref. 1, Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-19 to 3-22, P. 3-5 to 3-8). . . ☐
4. Shut down wafer aligner module. Switch off UV source and machine electric power. (Ref. 1, Ref. 5, Operator Instructions). ☐
5. Shut down developer module. Switch off system electric power. Clean drain cup and dispenser heads if necessary. (Ref. 1, Ref. 2, Fig. 3-1, P. 3-3, Sec. 3-19 to 3-22, P. 3-5 to 3-8). ☐
6. Switch off electric power to soft bake oven. (Ref. 1, Ref. 6, Sec. 2-10, P. 2-1, Fig 3-1, P. 3-3). ☐
7. Switch off electric power to bake oven. (Ref. 1, Ref. 7, Sec. 2-10, P. 2-1, Fig. 3-1, P. 3-2). ☐
8. Turn off vacuum supply to bake oven. (Ref. 7, Sec. 2-12). ☐
9. Turn off N_2 to soft bake and bake ovens. (Ref. 1, Ref. 6, Sec. 2-11, P. 2-1, Ref. 7, Sec. 2-11, P. 2-1). ☐
10. Turn off N_2 to coater and developer modules. (Ref. 1, Ref. 2, Fig. 2-1, P. 2-2). ☐


Long Term Shut Down

The following steps are done in addition to the short term shut down steps.

1. Remove photoresist fluid from the coater module reservoir. Flush reservoir, lines and head with solvent. Purge fluid system with N_2 . . . ☐

CAUTION: Face and hand protection required when handling or exposed to photo-resist fluid and solvents. (Ref. 4, P. 94-106 & 137).

2. Remove stoddard solvent and N-Butyl acetate solvent from reservoirs, lines and spray heads of the developer module. Purge solvent systems with N₂. ☐
3. Switch off main AC electric power supply. (Ref. 1). ☐
4. Turn off vent gas system. (Ref. 1). ☐
5. Normal maintenance and preventative maintenance is done after normal shut down. (Ref. 2, Sec. VI, P. 6-1 to 6-14, Ref. 3, Sec. V, P. 5-1 to 5-32, Ref. 5, Ref. 6 and 7, Sec. 5-1 and 5-2, P. 5-1 to 5-5). ☐



4-EMERGENCY SHUT DOWN STEPS

Chemical Problem Shut Down

This can be caused by localized ignition of solvent vapors or by fire in an adjacent area. These conditions will probably result in an aborted run.

1. Activate fire extinguisher system as needed. ☐
2. Shut down total vent gas system. (Ref. 1). ☐
3. Switch off main AC electric power. (Ref. 1). ☐
4. Turn off N_2 to coater, aligner, bake ovens, developer, buffer tees and wafer track. (Ref. 1). ☐
5. Drain and dispose of photoresist fluid in coater module and solvents in developer module. ☐

CAUTION: Face and hand protection required when handling or exposed to photoresist fluid and solvents. (Ref. 4, P. 94-106 and 137.)

6. Switch off electric power to individual modules in system. (Buffer tees, coater, soft bake oven, aligner, developer and bake oven). . . . ☐
(Ref. 1).
7. Turn off vacuum supply to bake oven. (Ref. 1). ☐
8. Inventory extent of damage. ☐

Electrical/Mechanical Problem Shut Down

This can be caused by power outages, electrical shorts and defects or malfunctions in mechanical and electrical equipment (Motors, solenoids, switches, Etc.).

1. Switch off electric power to individual modules in system. (Buffer tees, coater, soft bake, aligner, developer and bake). (Ref. 1). . . ☐

CAUTION: Check for possible electrical shock hazard. (Ref. 4, P. 79-93).

EDB

2. Shut down wafer track. ☐
3. Turn off vacuum supply to bake oven. (Ref. 7, Sec. 2-12). ☐
4. Turn off N₂ to individual modules in system. (Buffer tees, coater, soft bake, aligner, developer and bake). (Ref. 1). ☐
5. Inventory extent of defects and damage. ☐

C-3

5-EMERGENCY SHUT DOWN
CLEAN UP, INSPECTION AND REPAIR STEPS

1. Make sure main AC electrical power is switched OFF. (Ref. 1). . . . ☐
2. Clean up any fire extinguisher, solvent splash, or fire damage on modules or wafer track. ☐
3. Inspect/Test and repair electric cable and insulation damage. . . . ☐

CAUTION: Make sure all equipment is properly grounded. Make sure there are no electrical shorts. (Ref. 4, P. 79-93).

4. Selectively switch on electric power to each module in system. Check for proper operations of buffer tees, coater soft bake oven, aligner, developer and bake oven. ☐
5. Inspect, test and repair as needed the total vent gas system. . . . ☐
6. Do normal maintenance on each module in system. (Ref. 2, Sec. VI, P. 6-1 to 6-14, Ref. 3, Sec. V, P. 5-1 to 5-32, Ref. 5, Ref. 6 & 7, Sec. 5-1, and 5-2, P. 5-1 to 5-5). ☐
7. When system checks and required maintenance is completed, then either go to normal shut down steps or to Precondition/Calibration steps as needed. ☐

6-APPENDIX

1. Photolithography System Routine, MSFC, 1979.
2. Preliminary Operations and Maintenance Manual, In Line Coater/Developer, Model 6891/6892, Publication No. 029-325690, GCA/Sunnyvale Div., May 1974.
3. Preliminary Operations and Maintenance Manual, Buffer T, Model 6106, Publication No. 029-325688, GCA/Sunnyvale Div., May 1974.
4. Safety and Enviromental Health Standards, MM 1700. 4B, MSFC, October 15, 1974.
5. Operating Manual, Wafer Alignment System, Model 2001-A, Kasper Instruments Inc., Mountain View, Ca.
6. Preliminary Operations and Maintenance Manual, In Line IR Soft Bake Station Model 4111, GCA/Sunnyvale Div.
7. Preliminary Operations and Maintenance Manual, In Line IR Bake Station, Model 4112, GCA/Sunnvale Div.

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ICE
INTEGRATED CIRCUIT ENGINEERING CORPORATION
6710 East Camelback Road
Scottsdale, Arizona 85251 • (602) 945-4564

February 2, 1979

Mr. Ralph Grubb, Sr. Engineer
NASA Fabrication Laboratory
National Aeronautics & Space Administration
Geo. C. Marshall Space Flight Center
Huntsville, Alabama 35812

Dear Ralph:

Please find enclosed a brief report on the disposal of vent gasses from epitaxial reactors.

ICE recommends that burn-off procedures be used. Please also find attached a copy of a page from Motorola's safety handbook, which strongly supports ICE's recommendation.

Should you have any further questions, please do not hesitate to call me.

Yours truly,



Howard K. Dicken
Executive Vice President

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Enclosures

5. DISPOSAL OF EPITAXIAL VENT GAS

DISPOSAL OF VENT GAS FROM EPITAXIAL PROCESSING

Epitaxial processing of semiconductor wafer does produce a vent gas that has to be discarded in a safe manner. The main constituents of this gas are N_2 , and H_2 , with smaller sporadic amounts of PH_3 , B_2 , H_6 , AsH_3 , HCL , NH_3 , and N_2O . Safe disposal must consider the flammability of H_2 as well as the toxicity of the dopant gasses. The disposal techniques currently used by industry are dispersion and flaring. There are advantages to both of these techniques.

Dispersion

If satisfactory dilution can be safely achieved, then the dispersion technique will give adequate disposal. This does require that the H_2 be kept below the lower flammability limit ($< 4\%$ in air) and that the exhaust be kept away from the occupied facilities to avoid exposure to the residues of the dopant gasses. If these conditions can be achieved reliably, then this system does result in the lowest capital and operating cost. However, there is still an element of risk. In some areas of the exhaust system at certain times in the process sequence there will be sufficient H_2 in the air to be in the explosive range. If a source of ignition is present, then a hazardous condition will result. The composition of a flammable H_2 -air mixture is not significantly changed going through a scrubber. Thus using a scrubber is not a satisfactory way to eliminate

DISPOSAL OF VENT GAS

Page 2

a potential explosion hazard. Leaks in ducts or scrubber malfunctions can allow build-up of toxic dopant gasses. If a scrubber is not used and straight outside venting is employed then variations in atmospheric conditions can cause misdirection of the gas flow so that other work areas could be subject to toxic gas exposure.

Flaring

Burn-off of the vent gas as it is produced at the epitaxial module is the safest method of disposal. Deliberate controlled ignition does not rely on avoiding the explosive range of H_2 , but is always safe under any set of operating conditions. By converting the dopant gasses to oxides, the toxicity limits are increased, the possibility of harmful exposure with leaks is reduced, and removal of boron, phosphorous and arsenic in the scrubber is enhanced. Even if straight outside venting is done the harmful exposure is dramatically reduced. Flaring does increase the capital and operating costs, however, most of the more conservative, safety-conscious semiconductor manufacturers will opt for flaring because of its inherent reduction of risk. Some attempts have been made to recover H_2 gas for recycling in the process or the conservation of the H_2 thermal energy for process heat or space heating. Under present economic conditions, none of the proposed recovery systems have proven to be cost effective.

MOTOROLA INC.
Semiconductor Products Division

Technical Bulletin No. 28

HYDROGEN

FORMULA:	H_2
PHYSICAL STATE:	Colorless, odorless gas.
CORROSIVITY:	Noncorrosive.
REACTIVITY:	Can react vigorously with oxidizers.
FLASH POINT:	Combustible gas.
EXPLOSIVE LIMITS:	4.0% to 75.0% in air.
FIRE CONTROL:	Extinguish fire after shutting off source of gas. CO_2 or Dry Chemical are effective.
VENTILATION REQUIREMENTS:	Local exhaust, and enclosure of process equipment is required.
HEALTH HAZARD:	May cause asphyxiation by displacing Oxygen in an enclosed space.
STORAGE REQUIREMENTS:	Storage in compressed gas cylinders, (See Safety Instruction No. 6 & 106.)
SPECIAL PRECAUTIONS:	All furnaces using Hydrogen shall be equipped with automatic purge and burn-off devices.

6. SUMMARY REPORT

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ICE
INTEGRATED CIRCUIT ENGINEERING CORPORATION
6710 East Camelback Road
Scottsdale, Arizona 85251 • (602) 945-4564

September 4, 1979

Mr. Ralph Grubb
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Dear Ralph:

Attached please find a final safety report on your new facility expansion. The recommendations in the summary are:

1. The CVD reactor effluent gases should go to an exit stack and out to a specially designed shower burn-box that we described to you on our visit. The sketch for the shower burn-box is attached and is designed by Dr. Jim Fordemwalt.
2. A scrubber should be connected to your epi exit gases which should include an H_2 burn-box located in the scavenger box of each epi furnace. These H_2 burn boxes are available from Thermco Products, 1465 North Batavia Street, Orange, California, Phone 714 639 2340. Contact: Jim Rhodes.
3. The third separate line coming out of your facility should be an ammonia line (open NH_3). The ammonia line should be on a separate exit and should not mix with $SiCl_4$ (Silicon Tetrachloride). For specific detail, please see the attached.

Sincerely,



Daniel J. Shelton
Senior Staff Engineer
md
Enclosure

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INTEGRATED CIRCUIT ENGINEERING CORPORATION

**RESEARCH STUDY:
HAZARD AND OPERATIONS
ANALYSIS OF FACILITY
FOR ELECTRONIC DEVELOPMENT**

FINAL REPORT

PREPARED FOR

**GEORGE C. MARSHALL SPACE FLIGHT CENTER, NASA
MARSHALL SPACE FLIGHT CENTER, ALABAMA**

**PREPARED BY
INTEGRATED CIRCUIT ENGINEERING CORPORATION
6710 EAST CAMELBACK ROAD
SCOTTSDALE, ARIZONA
602-945-4564**

SEPTEMBER 1979

SUMMARY FOR FACILITIES INSTALLATIONS

1. To dispose of silane which has a molecular weight of 32.112, has a density of 1.44 gr/l and is pyrophoric (burns in air), the following are conditions for disposing of silane correctly:

Silane should be burned in a remote location through a steam burn-box. The silane should be piped from the CVD reactor to a remote location and exhausted under a shower of water to burn. Other gases that are evolving from the CVB reactor should be treated in the same manner. Those gases are phosphine, argon, nitrous oxide, ammonia, nitrogen, diborane, dichlorosilane and hydrogen chloride.

2. The effluent gas from the epitaxial reactor should go to an adequate scrubber. The hydrogen may be exhausted into a scavenger box and burned, if necessary. Alternatively, it may be mixed with an adequate volume of air to ensure that it never reaches an explosive mixture.
3. The use of Baccharach hydrogen sensors in the line stack are recommended to monitor the hydrogen-oxygen ratio. Hydrogen-oxygen mixtures are explosive at percentage mixtures of from 4 percent to 75 percent.
4. A separate warning panel at your location C-180A for hydrogen sensing and other gas identification. This annunciator panel would give a "what's wrong" alarm indicator in the event if alarm bells are activated. A typical system for this is the Foxborough ID system that Ralph Grubb and ICE discussed during our visit.
5. The concrete protection posts are recommended outside your remote gas storage building, on the north side of the building next to the street. These posts are similar in concept to the ones that are located near the nitrogen tanks across from building 4476.

The scrubber to be used for the main epi gas exhaust is a Ducon-Savko from Beaver Falls, Oregon. The proper stack size is 16" diameter, and it should rise 8' above the building top. The scrubber that you have for the CVD system is a Paramount scrubber. It appears to be very adequate for the job. We would recommend that the Paramount scrubber, manufactured by Paramount Plastics Fabricators, in Downey, California, have heaters to prevent freeze-up in winter and be in a lean-to.

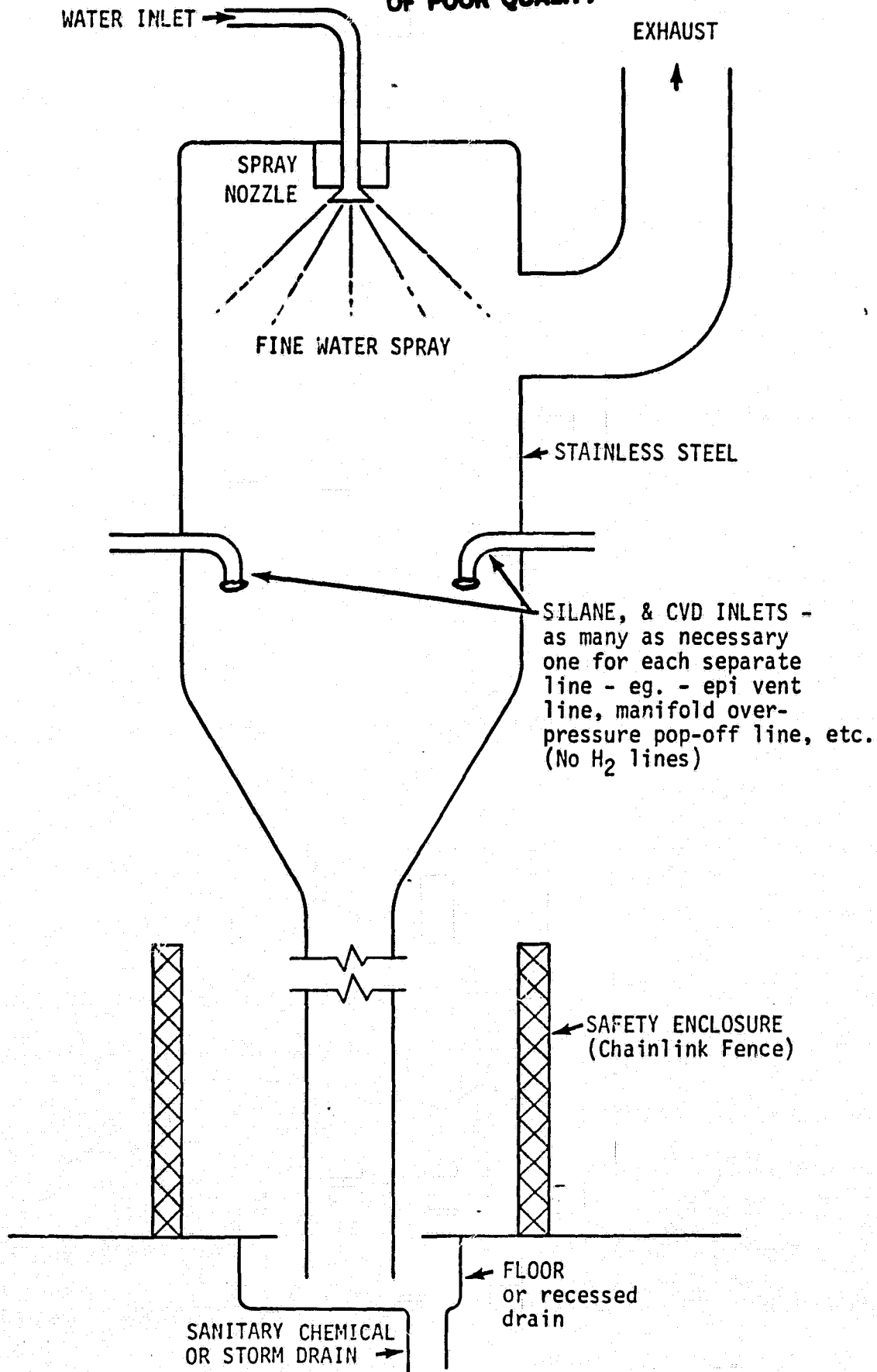
INTEGRATED CIRCUIT ENGINEERING CORPORATION

ICE would recommend that the air flow tunnels between the gas storage building and your main facility have air flow sensors installed in them. The relay-pulsed flow sensor that Ralph Grubb mentioned would be an appropriate model to use. Portable sniffers are also recommended to check for any leaks from the origin gas building into epi reactor or CVD reactor. We would also recommend that you seal all air ducts and that they be stainless steel and preferably heliarc welded.

In general, ICE will provide and continue to provide literature and information that is required to make your NASA facility as safe as humanly possible. We also have training seminars, and other employee acquaintance procedures that would be in your best interest to pursue. In conversations with Bobby Kennedy and Ralph Grubb, ICE has proposed a separate startup and training project to acquaint all your employees with the use and handling of dangerous gases or other gases that relate to IC manufacture. Basically, education is as much as important part for good safety as any mechanical safety interlock or warning device.

Pursuing an avenue where the computer can take each system to standby is another very good option. As discussed with Mike Martin, Ralph Grubb, et al, it was proposed that all equipment should be nitrogen purged in the event of a system malfunction.

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ADDENDUM
TO
FACILITY SAFETY STUDY

A REPORT FOR NASA
MARSHALL SPACE FLIGHT CENTER
CONTRACT # NAS8-32812

PREPARED BY
INTEGRATED CIRCUIT ENGINEERING CORPORATION
6710 EAST CAMELBACK ROAD
SCOTTSDALE, ARIZONA 85251

(602) 945-4564

APRIL 1980

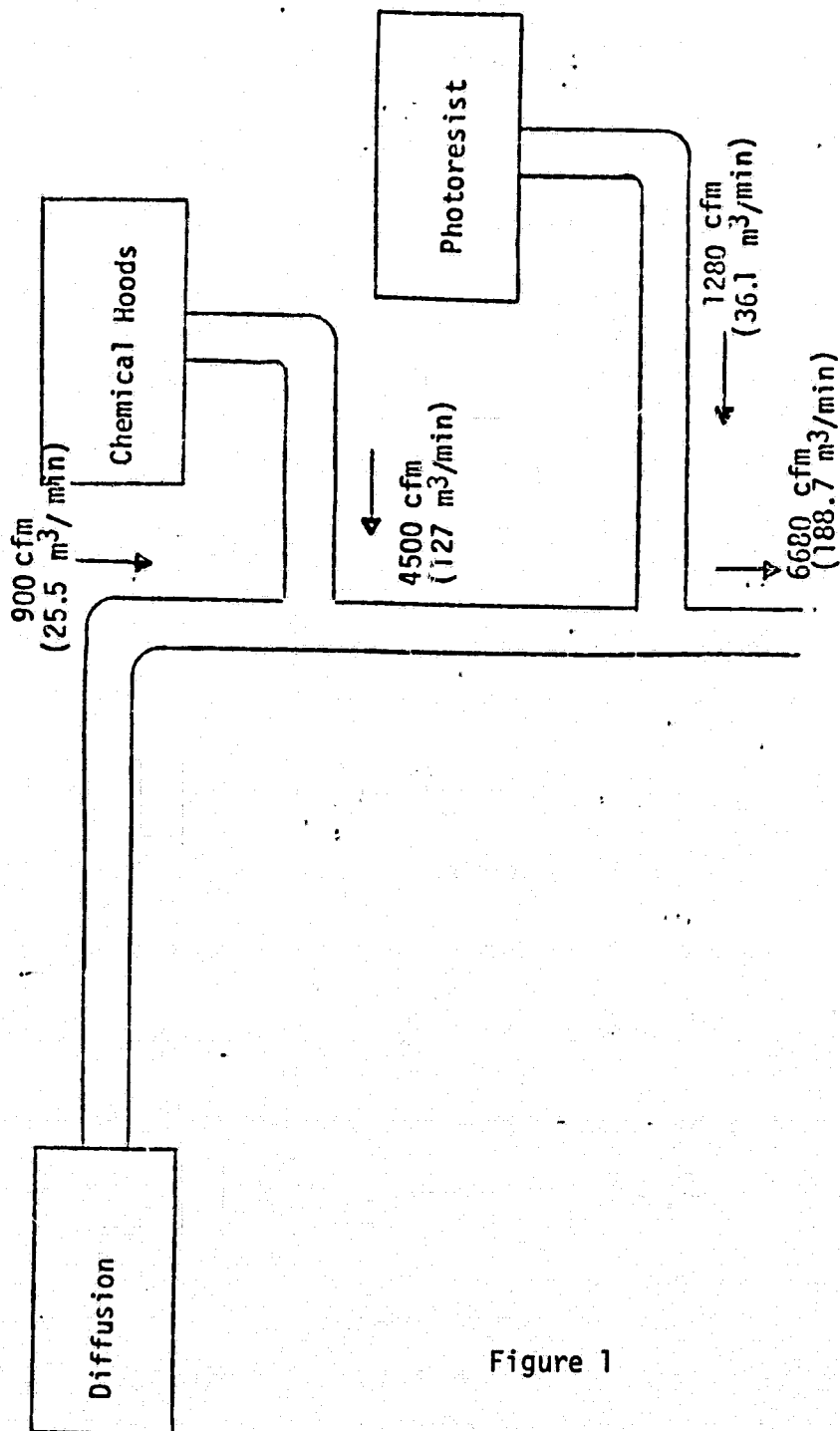
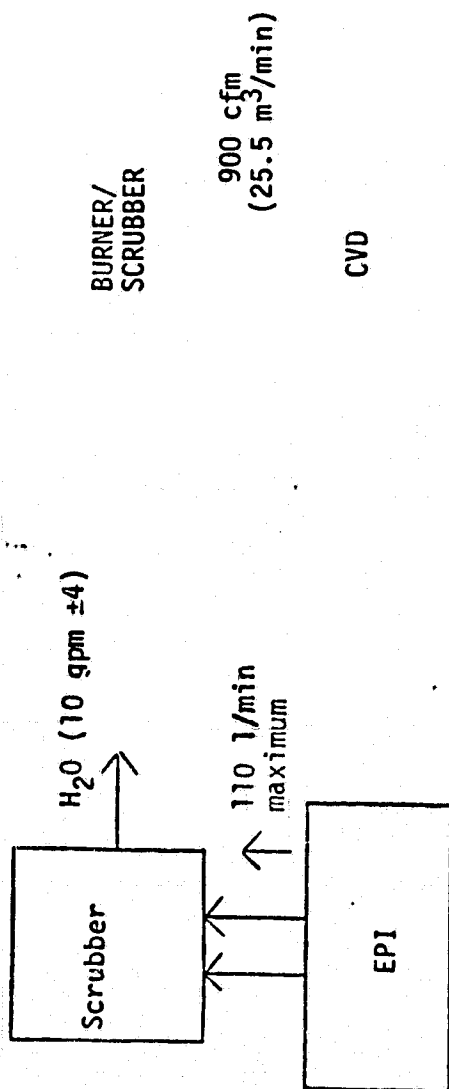
1. BACKGROUND

The following is an initial report on the emission control requirements for the FED operation, which is located at the NASA facility in Huntsville, Alabama. This work was requested by Mr. Ralph Grubb, and is part of Contract No. NAS8-32812. This study and initial report involves the determination of the safety of the present exhaust gas system of the laboratory, and other equipment would be required to meet acceptable industry and OSHA standards. The following report presents the detailed calculations and ICE's recommendations.

To provide more flexibility in the use of the data, the laboratory was divided into four sections, as shown on the attached chart. Calculations for each section were made individually, in addition calculations are made on the combined results to allow for any unique chemical combinations which might occur during exhaust gas mixing. These areas are as follows:

- (a) Diffusion
- (b) Etch Stations (Chemical Hoods)
- (c) Photoresist
- (d) Epi
- (e) CVD

The specific assumptions and backgrounds are given under each section.



FED AIR FLOW SYSTEM

Figure 1

2. SUMMARY

Based upon the chemical and air-flow data, as supplied by NASA, the present exhaust system, which includes the diffusion, etch stations, and photoresist operations, will exceed OSHA limits for two materials and be near the OSHA limit for one other, as shown in Figure 2.

Calculations were based both on normal operations and worst case conditions. As shown in Figure 3, under normal operations the acetone and trichlorethylene from the etch station area will exceed OSHA limits. Thus, ICE would recommend the insulation of a gas scrubber to handle this exhaust system. This facility would then be compatible, with semiconductor practices with regard to safety and pollution control.

Figure 4 shows that the exhaust directly from the etch facility also exceeds OSHA limits for acetone and TCE. The exhaust from the photoresist area of approximately 1280 cubic feet per minute ($36 \text{ m}^3/\text{min}$), is sufficient and none of the chemicals will exceed OSHA limits.

Figure 5 is a summary of the total combined exhaust from the system.

The epitaxial area was treated separately because it did have a separate exhaust system. Figure 6 shows that six chemicals in the epitaxial area will exceed OSHA limits. These are ammonia, hydrogen chloride, nitrous oxide, diborane, phosphine, and arsine. This confirms the requirement of the scrubber for that system which has already been ordered and is now being installed. Additional studies also show that the epitaxial exhaust will need a hydrogen burn-off.

Figure 7 shows the two chemicals in the CVD area that exceed OSHA limits. These are dichlorosilane and hydrogen chloride. This effluent should go to a separate burn box shower for disposal.

FIGURE 2

CRITICAL MATERIALS

1. OVER OSHA LIMITS
 - (A) ACETONE
 - (B) TRICHLORETHYLENE
2. NEAR OSHA LIMITS
 - (A) SULFURIC ACID

FIGURE 3

CRITICAL AREAS

TOTAL FACILITY (ETCH, PHOTORESIST, DIFFUSION)

<u>MATERIAL</u>	<u>EMISSIONS, mg/m^3</u>		
	<u>NORMAL OPERATION</u>	<u>WORSE CASE OPERATION</u>	<u>OSHA LIMITS</u>
1. ACETONE	2953	-	2400
2. TRICHLORETHYLENE	2338	-	535

FIGURE 4

CRITICAL AREAS
ETCH FACILITY

<u>MATERIAL</u>	<u>EMISSIONS, mg/m^3</u>	
	<u>NORMAL OPERATION</u>	<u>OSHA LIMITS</u>
1. ACETONE	2953	2400
2. TCE	2338	535

Figure 5

Combined Total Emissions From Etch Stations, Diffusion Stations, and Photoresist Stations

ETCH FACILITY		HYDROFLUORIC ACID HF	HYDROCHLORIC ACID HCl	NITRIC ACID HNO ₃	SULFURIC ACID H ₂ SO ₄	PHOSPHORIC ACID H ₃ PO ₄	ACETIC ACID CH ₃ COOH	ACETONE	TRICHLOR ETHYLENE	PROPANOL	XYLENE	STANDARD SOLVENT	BUTYL ACETATE	DIBORANE B ₂ H ₆	PHOSPHINE PH ₃
Normal Case		0.69	0.002	0.510	0.056	0.009	2.8	1139	399	45.4					
EPT		0.79	0.004	1.74	0.785	0.037	7.6	2953	2338	122					
Worst Case		1.45	0.732	318	144	6.77	1390	540,000	428,000	22,300					
g/day															
DIFFUSION FACILITY															
Normal Case															
EPT															
Worst Case															
g/day															
PHOTORESIST FACILITY															
Normal Case															
EPT															
Worst Case															
g/day															
CORE FACILITY EXHAUST															
Normal Case															
EPT															
Worst Case															
g/day															
CVD LIMITS															
EPT															
Problem Areas															

NOTE: This table does not include emissions from the EPT or CVD stations.

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FIGURE 6

CRITICAL AREAS
EPITAXY OPERATIONS

MATERIAL	EMISSIONS, mg/m^3	
	WORSE CASE OPERATION	OSHA LIMITS
1. AMMONIA	500,000	50
2. HYDROGEN CHLORIDE	750,000	5
3. NITROUS OXIDE	25,300	25
4. DIBORANE	1.29	.1
5. PHOSPHINE	1.29	.3
6. ARSINE	1.29	.05

FIGURE 7
CRITICAL AREAS
CVD OPERATIONS

<u>MATERIAL</u>	<u>EMISSIONS, MG/M³</u>	
	<u>WORSE CASE OPERATION</u>	<u>OSHA LIMITS</u>
1. DICHLOROSILANE	10.2	7
2. HYDROGEN CHLORIDE	38.4	7

3. ASSUMPTIONS

The conclusions and recommendations of this report are based upon raw data supplied by NASA with regard to typical and maximum gas flows on normal equipment usage. This data has not been confirmed or checked by ICE. ICE's calculations are based upon both typical and worse case conditions. Detailed assumptions as to gas flow and usage are given in the individual sections.

4

DIFFUSION

AND

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4. DIFFUSION

Included in this group are the diffusion furnances consisting of six tubes. The basic assumptions are given in Figure 8. It is assumed that the total vent flow from this area is 25.5 cubic meters per minute. Normal operation assumes that one tube is operating for each type of dopant. Worst case conditions assumes two tubes. Normal conditions for HCl cleaning assumes two tubes. The worst case condition assumes all six tubes. The various chemicals used in this system is listed in the following calculations.

Figure 9 is the summary of the chemical outputs from this particular system. It should be noted that OSHA limits for hydrogen chloride are exceeded at the output of this system, but are not exceeded when this system is fully diluted at the total facility exhaust output.

5. CVD

During the inspection of this facility it was noted that the output of the CVD reactor was not protected with ventilation or a hood. If the glass chamber would break, during the reactor operation the chemicals could quickly disperse into the room. It is, thus, recommended that that end of the CVD reactor be included in a vent or hood arrangement.

Included in this system is the CVD system with two chambers. Normal operations assume that one chamber is operating, while worst case assumes two. The various chemicals used in this system are listed in the following calculations. Figure 9A is a summary of the chemical outputs from this system.

FIGURE 8

DIFFUSION OPERATION ASSUMPTIONS

2 Tubes Phosphine, 1% PH_3 in Argon (Nitrogen)

87cc/min Diluted with 11.2 l/min of Inert Gas

2 Tubes Diborane, 0.1% B_2H_6 in argon (Nitrogen)

87cc/Min Diluted with 5 l/min of Inert Gas

2 Oxidation Tubes

HCl Gas for Tube Cleaning - 15% in O_2 99.999% HCl

HCl Gas Flow is 500 cc/min

Assume Normal 2, maximum of 6 tubes cleaned at one time.

Total Vent Flow 25.5 m^3/min - No Dilution with CVD

Average Clean 300cc/min

Final Dilution with Total Exhaust

$$\frac{25.5 \text{ m}^3/\text{min}}{188.7 \text{ m}^3/\text{min}} = .135 \text{ Diffusion and CVD Dilution Factor}$$

FIGURE 9
DIFFUSION OPERATIONS EMISSIONS

	<u>HYDROGEN CHLORIDE HCL</u>	<u>DIBORANE B₂H₆</u>	<u>PHOSPHINE PH₃</u>
<u>DIFFUSION FACILITY</u>			
<u>NORMAL CASE</u>			
PPM	5.89*	.003	.034
MG/M ³	9.59*	.004	.052
G/DAY	351	.14	1.9
<u>WORST CASE</u>			
PPM	17.7*	.007	.068
MG/M ³	28.8*	.008	.104
G/DAY	1053	.28	3.8
<u>OSHA LIMITS</u>			
PPM	5	.1	.3
MG/M ³	7	.1	.4

*EXCEEDS OSHA LIMITS

FIGURE 9A
CVD OPERATIONS EMISSIONS

	DICHLORO- SILANE SiH_2Cl	AMMONIA NH_3	HYDROGEN CHLORIDE HCl	NITROUS OXIDE N_2O	DIBORANE B_2H_6	PHOSPHINE PH_3
<u>CVD FACILITY</u>						
<u>NORMAL CASE</u>						
PPM	3.14	3.14	11.8*	3.92	.078	.078
MG/M^3	5.1	2.39	19.2*	7.7	.097	.119
G/DAY	187	87.8	703	282	140	
<u>WORST CASE</u>						
PPM	6.28*	6.28	23.6*	7.85	.156	.156
MG/M^3	10.2*	4.78	38.4*	15.4	.194	.238
G/DAY	374	176	1400	564	279	
<u>OSHA LIMITS</u>						
PPM	5	50	5	25(tent)	.1	.3
MG/M^3	7	35	7	-	.1	.4

*EXCEEDS OSHA LIMITS